Acerca de este libro

Esta es una copia digital de un libro que, durante generaciones, se ha conservado en las estanterías de una biblioteca, hasta que Google ha decidido escanearlo como parte de un proyecto que pretende que sea posible descubrir en línea libros de todo el mundo.

Ha sobrevivido tantos años como para que los derechos de autor hayan expirado y el libro pase a ser de dominio público. El que un libro sea de dominio público significa que nunca ha estado protegido por derechos de autor, o bien que el período legal de estos derechos ya ha expirado. Es posible que una misma obra sea de dominio público en unos países y, sin embargo, no lo sea en otros. Los libros de dominio público son nuestras puertas hacia el pasado, suponen un patrimonio histórico, cultural y de conocimientos que, a menudo, resulta difícil de descubrir.

Todas las anotaciones, marcas y otras señales en los márgenes que estén presentes en el volumen original aparecerán también en este archivo como testimonio del largo viaje que el libro ha recorrido desde el editor hasta la biblioteca y, finalmente, hasta usted.

Normas de uso

Google se enorgullece de poder colaborar con distintas bibliotecas para digitalizar los materiales de dominio público a fin de hacerlos accesibles a todo el mundo. Los libros de dominio público son patrimonio de todos, nosotros somos sus humildes guardianes. No obstante, se trata de un trabajo caro. Por este motivo, y para poder ofrecer este recurso, hemos tomado medidas para evitar que se produzca un abuso por parte de terceros con fines comerciales, y hemos incluido restricciones técnicas sobre las solicitudes automatizadas.

Asimismo, le pedimos que:

+ *Haga un uso exclusivamente no comercial de estos archivos* Hemos diseñado la Búsqueda de libros de Google para el uso de particulares; como tal, le pedimos que utilice estos archivos con fines personales, y no comerciales.

+ *No envíe solicitudes automatizadas* Por favor, no envíe solicitudes automatizadas de ningún tipo al sistema de Google. Si está llevando a cabo una investigación sobre traducción automática, reconocimiento óptico de caracteres u otros campos para los que resulte útil disfrutar de acceso a una gran cantidad de texto, por favor, envíenos un mensaje. Fomentamos el uso de materiales de dominio público con estos propósitos y seguro que podremos ayudarle.

+ *Conserve la atribución* La filigrana de Google que verá en todos los archivos es fundamental para informar a los usuarios sobre este proyecto y ayudarles a encontrar materiales adicionales en la Búsqueda de libros de Google. Por favor, no la elimine.

+ *Manténgase siempre dentro de la legalidad* Sea cual sea el uso que haga de estos materiales, recuerde que es responsable de asegurarse de que todo lo que hace es legal. No dé por sentado que, por el hecho de que una obra se considere de dominio público para los usuarios de los Estados Unidos, lo será también para los usuarios de otros países. La legislación sobre derechos de autor varía de un país a otro, y no podemos facilitar información sobre si está permitido un uso específico de algún libro. Por favor, no suponga que la aparición de un libro en nuestro programa significa que se puede utilizar de igual manera en todo el mundo. La responsabilidad ante la infracción de los derechos de autor puede ser muy grave.

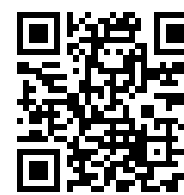
Acerca de la Búsqueda de libros de Google

El objetivo de Google consiste en organizar información procedente de todo el mundo y hacerla accesible y útil de forma universal. El programa de Búsqueda de libros de Google ayuda a los lectores a descubrir los libros de todo el mundo a la vez que ayuda a autores y editores a llegar a nuevas audiencias. Podrá realizar búsquedas en el texto completo de este libro en la web, en la página `http://books.google.com`

This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

Google™ books

https://books.google.com



Digitized by Google

THE LIBRARY
OF

CLASS En 620.6
BOOK Am32

Digitized by Google

Digitized by Google

UNIVERSITY OF MINNESOTA
THE LIBRARY
Je 30 1911
RECEIVED

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 7

July, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Annual Convention, Chicago, June 26-30, 1911 - 217
Electric Light Convention - 219
Applications for Election - 220
Past Section Meetings - 220
Past Branch Meetings - 222
Personal - 225
Obituary - 225
Library Accessions - 225

Section II. Papers, Discussions, and Reports

(PAPERS FOR ANNUAL CONVENTION, JUNE 26-30, 1911.)

The Mechanical and Electric Characteristics of Transmission Lines. By Harold Pender and H. F. Thomson - 1379
Transmission System of the Great Western Power Company. By J. P. Jollyman - 1417
Transmission System of the Southern Power Company. By W. S. Lee - 1421
Transmission Systems of the Great Falls Power Company. By M. Hibgen - 1425
Some Recent Tests of Oil Circuit Breakers. By E. B. Merriam - 1431
Development of the Modern Central Station. By Charles Proteus Steinmetz - 1449
The Commercial Loading of Telephone Circuits in the Bell System. By Bancroft Gherardi - 1463
The Law of Corona and the Dielectric Strength of Air. By F. W. Peek, Jr - 1485
Automatic Motor Control for Direct Current Motors. By Arthur C. Eastwood - 1563
Elevator Control. By T. E. Barnum - 1583
Some Limitations of Rheostatic Control. By G. R. Radley and L. L. Tatum - 1605
Electric Line Oscillations. By G. Faccioli - 1621
The Use of Power-Limiting Reactances with Large Turbo-alternators. By R. F. Schuchardt and E. O. Schweitzer - 1669

Report of Library Committee - 1721

Index to Advertisements - iii

Copyright 1911, by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

READY IN JUNE

352 Pages **6x9 Inches** **139 Illustrations**

Electric Central Station Distribution Systems

Their Design and Construction

BY

HARRY BARNES GEAR, A.B., M.E.

Associate, American Institute of Electrical Engineers

AND

PAUL FRANCIS WILLIAMS, E.E.

Associate, American Institute of Electrical Engineers

A THOROUGH, lucid treatment of the general field of distribution from the standpoint of American practice for engineers and students. The treatment is based upon the assumption of a general knowledge of electrical theory such as is possessed by the more advanced students of engineering and by men in practical distribution engineering work. Much of the subject matter of the book is, however, of such a nature as to be easily grasped by practical men who have not had a full theoretical training.

CONTENTS.

CHAPTER I. Systems of Distribution. II. Transmission and Conversion. III. Voltage Regulation. IV. Line Transformers. V. Secondary Distribution. VI. Special Schemes of Transformations. VII. Protective Apparatus. VIII. Overhead Construction: Pole Work. IX. Overhead Construction: Lines and Accessories. X. Underground Construction. XI. Cable Work. XII. Distribution Economics. XIII. Properties of Conductors. XIV. Alternating Current Circuits.

D. VAN NOSTRAND COMPANY

PUBLISHERS AND BOOKSELLERS

23 Murray and 27 Warren Streets - - New York

Digitized by Google

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **July, 1911** No. 7

Annual Convention Chicago June 26-30, 1911

The twenty-eighth Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS will be held in Chicago, Ill., June 26, 27, 28, 29 and 30, 1911.

Institute Headquarters

The Institute headquarters during the convention will be at the Hotel Sherman, corner of Randolph and Clark Streets. On arrival at the hotel each member should register and obtain an identification badge. The convention sessions will be held in the hotel. The following program has been arranged.

PROGRAM.

Monday, June 26

8:30 P.M.

Reception and dance, Grand Ball Room, Hotel Sherman.

Tuesday, June 27

POWER STATION SESSION

10:00 A.M.

1. President's Address, *Electrical Engineers and the Public*, by Dugald C. Jackson.
2. Introduction of President-Elect, Gano Dunn.
3. *Development of the Modern Central Station*, by C. P. Steinmetz.
4. *Tests of Oil Circuit Breakers*, by E. B. Merriam.
5. *The Use of Power Limiting Reactances with Large Turbo-Alternators*, by R. F. Schuchardt and E. O. Schweitzer.

1:30 P.M.

Luncheon at Western Electric Company's Hawthorne Works, followed by visits to Commonwealth Edison Company's power houses.

ELECTRIC LIGHTING SESSION

8:30 P.M.

6. *Depreciation as Related to Electrical Properties*, by Henry Floy.
7. *Important Features Entering Into Making of Appraisals*, by H. M. Byllesby.

Wednesday, June 28.

RAILWAY SESSION

10:00 A.M..

8. *Electrical Operation of the Electrified Portion of the West Jersey and Seashore Railroad*, by B. F. Wood.
9. *Analysis of Electrification*, by W. S. Murray.
10. *Induction Machines for Heavy Single-Phase Motor Service*, by E. F. W. Alexanderson.

INDUSTRIAL POWER SESSION

2:30 P.M.

11. *Automatic Motor Control for Direct-Current Motors*, by Arthur C. Eastwood.
12. *Limitations of Rheostat Control*, by L. L. Tatum.
13. *Control of High Speed Electric Elevators*, by T. E. Barnum.
14. *Electrically Driven Reversing Rolling Mills*, by Wilfred Sykes.

PARALLEL MEETING

TELEGRAPHY AND TELEPHONY SESSION

2:30 P.M.

15. *Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires*, by George O. Squier.
16. *Telegraph Transmission*, by F. F. Fowle.

UNIV 331533 LIBRARY
Digitized by Google

17. *Commercial Loading of Telephone Circuits in the Bell System*, by Bancroft Gherardi.
17-A. *Problems in Telephone Traffic Engineering*, by F. P. Valentine.

EVENING

Boat trip on Lake Michigan.

Thursday, June 29.

HIGH TENSION TRANSMISSION SESSION
10:00 A.M.

18. *Dielectric Strength of Air*, Part II, by J. B. Whitehead.
19. *The Law of Corona and the Dielectric Strength of Air*, by F. W. Peek, Jr.
20. *Transmission System of the Great Western Power Company*, by J. P. Jollyman.
21. *Transmission System of Southern Power Company*, by W. S. Lee.
22. *Transmission System of the Great Falls Power Company*, by M. Hibgen.
23. *Electric Line Oscillations*, by G. Faccioli.

2:30 P.M.

Visit to Indiana Steel Company's plant, Gary, Indiana.

8:30 P.M.

(Under auspices of Sections Committee)

Conference of Institute officers and Section delegates.

Friday, June 30.

GENERAL SESSION
10:00 A.M.

24. *Economical Design of Direct-Current Electro-Magnets*, by R. Wikander.
25. *Electrolytic Corrosion in Reinforced Concrete*, by C. E. Magnusson and G. H. Smith.
26. *Wave Shape of Currents in an Individual Rotor Conductor of a Single-Phase Induction Motor*, by H. Weichsel.
27. *The Choice of Rotor Diameter and Performance of Polyphase Induction Motors*, by Theodore Hoock.
28. *The Application of Current Transformers in Three-Phase Circuits*, by J. R. Craighead.
29. *The Cost of Transformer Losses*, by E. C. Stone and R. W. Atkinson.

PARALLEL MEETING
HIGH-TENSION TRANSMISSION SESSION
10:00 A.M.

30. *Solution to Problems in Sags and Spans*, by W. L. R. Robertson.
31. *Sag Calculations for Suspended Wires*, by P. H. Thomas.
32. *Mechanical and Electrical Characteristics of Transmission Lines*, by Harold Pender and H. F. Thomson.
33. *The High Efficiency Suspension Insulator*, by A. O. Austin.

EDUCATIONAL SESSION
2:30 P.M.

34. *Tentative Scheme of Organization and Administration of a State University*, by Ralph D. Mershon.

ADJOURNMENT

Entertainment

The week's entertainment will include the following:

Monday, June 26, 8.30 p.m. A general reception will be held at the Hotel Sherman at 8.30 p.m., followed by dancing. Light refreshments will be served.

Tuesday afternoon, June 27. Circular inspection tour. Arrangements have been made to convey the members from the Hotel Sherman at the close of the Tuesday morning session to a special train leaving the Union Station at 12.55 p.m. for the Hawthorne Works of the Western Electric Company, where luncheon will be served at 1.30 p.m., after which a visit through the works will be made. At 3.30 p.m. the special train will leave the Hawthorne Works, conveying the members to the steam turbine power houses of the Commonwealth Edison Company at Fisk and Quarry Streets. The train will leave Fisk Street at about 5.30 p.m., arriving at the Union Station in time for the members to reach the Hotel Sherman at six o'clock.

Wednesday, June 28, 1.00 p.m. Luncheon to members at the Hotel

Digitized by Google

Sherman as guests of the Electric Club of Chicago. This will be at the hotel where the business sessions are held and will be between the morning and afternoon sessions.

Wednesday, June 28, 2.00 p.m. A reception, gallery tour and tea at the Art Institute, for the ladies. All the visitors and the ladies of the families of the local members are invited to attend this reception.

Wednesday, June 28, 8.15 p.m. Boat trip on Lake Michigan for ladies and gentlemen. The " United States ", one of the finest steamers on the Great Lakes, has been chartered for the exclusive use of members during the evening. The dock is but two blocks from the Hotel Sherman, and all are invited to board the boat at 7.30 p.m. It will sail at 8.15 o'clock, returning to the dock at about 11 o'clock. Two orchestras will furnish music; one for dancing on the deck set aside for that purpose, and another for special entertainment which has been arranged. If the weather should be such as to interfere with the sail on the lake, the party will be entertained on the boat at the dock, as arrangements have been made to insure comfort and pleasure regardless of the weather.

Thursday, June 29, 11.00 a.m. Luncheon for the visiting ladies at the South Shore Country Club. Automobiles will leave the Hotel Sherman at 11.00 o'clock and the ladies will be taken through the South Parks, arriving at the club where luncheon will be served at 1.00 p.m. Special entertaining features have been provided. Automobiles upon return will take the ladies to their respective hotels.

Thursday, June 29, 1.50 p.m. The members will go by special train to Gary, Indiana, where arrangements have been made for a tour of inspection of the famous and interesting electrically operated rolling mill.

Through the courtesy of several of the golf clubs in and about Chicago, arrangements have been made whereby visitors may avail themselves of the privileges of the clubs.

Representatives of the Entertainment Committee may be found at the office of the Secretary of the Institute on the second floor of the Hotel Sherman at all hours during the week, prepared to give full information concerning any of these events.

Hotel Accommodations

As heretofore, each member should arrange for his own hotel accommodations, and correspondence in regard to reservations should in all cases be directed to the hotel management.

Transportation.

It has not been possible to obtain special transportation rates for this convention. Members should therefore consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

Registration.

Each member and guest, upon registration, will receive a badge bearing his or her name, to be worn during the convention for the purpose of identification. The registration headquarters will be on the second floor of the Hotel Sherman, and the members are earnestly requested to co-operate with the Secretary by registering themselves and their guests promptly on arrival.

Electric Light Convention

The thirty-fourth convention of the National Electric Light Association held in the Engineers' Building, New York, was successful beyond the expectations of its officers. The registration of 5,438 was the highest point of attendance yet reached at an electrical gathering. With 70 papers and reports to be presented and discussed the sessions of the four days, May 29 to June 2 inclusive required the use of two assembly halls in addition to the auditorium. The facilities of the building

Digitized by Google

were practically equal to the demand upon them, but all arrangements had been well planned, and there was a general feeling of satisfaction with the careful attention to details which added so much to the comfort of all. The appreciation of this experience was conveyed to the founder societies in the following preamble and resolution unanimously adopted at the closing session of the convention.

Whereas, in occupying the United Engineering Building through the week, this Association has thrown a tremendous strain upon its resources, and,

Whereas, the sister engineering societies occupying the building have been most considerate and thoughtful under these unwonted conditions and have extended generous hospitality in every way,

Resolved, that the thanks of this Association be tendered to these societies with a hearty expression of desire for their prosperity and growth as occupants of this building for engineering.

Members and Associates of the Institute to the number of 450 were included in the attendance, many of whom visited headquarters and the library for the first time.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before July 20, 1911.

10541 Behrens, E. L., Toronto, Ont.
10542 Douglas, J. A., Winnipeg, Man.
10543 Johnson, E., Westeras, Sweden.
10544 Johnstone, R. J., Torres, Sonora, Mex.
10545 Neumayer, A., Belleville, Ill.
10546 Paulsen, M. H., Chicago, Ill.
10547 Raven, H. W., Chicago, Ill.
10548 Scherner, J., Milwaukee, Wis.
10549 Sullivan, P. F., Chicago, Ill.
10550 Brumelle, H. E., New York City.
10551 Bruen, G. E., New York City.
10552 Hodge, W. H., Chicago, Ill.
10553 Lightfoot, E. N., New York City.
10554 McKnight, C. H., Pittsburgh, Pa.
10555 Merritt, R. A., Toronto, Ont.
10556 Takahashi, M., Tokio, Japan.
10557 Toeppen, M. K., St. Louis, Mo.
10558 Blakeslee, D.W., Wilkinsburg, Pa.
10559 Brown, F. B., Montreal, Quebec.
10560 Eisenmenger, H. E., Cleveland, O.
10561 Gent, E. W., Morristown, N. J.
10562 Howard, C. D., Wellesville, N. Y.
10563 Smith, E. L., Louisiana, Mo.
10564 Stannard, H. H., New York City.
10565 Rutledge, H. H., Minneapolis, Minn.
10566 Ryan, J. T., San Francisco, Cal.
10567 Fitzpatrick, F. J., Bronx, N. Y.
10568 Henschel, O. H., Milwaukee, Wis.
10569 Martin, D. S., Schenectady, N.Y.
10570 Richardson, C. R., Boston, Mass.
10571 Pack, R. F., Toronto, Ont.
10572 Vinson, S. G., Mansfield, Ohio.
10573 Graf, R. J., Chicago, Ill.
10574 Edkins, E. A., Chicago, Ill.
10575 Buckard, C. A., Montreal, Que.
10576 Myrick, G. H., Chicago, Ill.
10577 Qualls, W. F., Greensburg, Ind.
10578 Sidler, L. J., Buenos Aires, A. R.
10579 Sutton, G. C., Spirit Lake, Idaho.
10580 Vianna, J. G., Rio de Janeiro, Brazil.
10581 Dickieson, A. L., Peterboro, Can.

Total, 41.

Past Section Meetings

Chicago

A joint meeting of the Chicago Section and the Electrical Section of the Western Society of Engineers was held in Chicago on Wednesday evening, May 24. Mr. Sameul G. McMeen, of McMeen and Miller, Chicago, presented a paper entitled "Notes on a Telephone System Recently Built in San Francisco and Its Neighborhood." Mr. McMeen described in detail many construction features of the Home Telephone Company's automatic system in San Francisco, on which he spent four years in making the designs and constructing the plant, and the last year in supervising its operation. The paper was discussed by Messrs. W. Lee Campbell, F. H. Reed, George Tanner,

Digitized by Google

Arthur B. Smith, W. H. Smythe, Albert Scheible, and J. G. Wray.

CLEVELAND

The annual meeting and dinner of the Cleveland Section was held at the University Club, Cleveland, on May 22. Sixty-four members and guests were present. The guest of honor was Mr. Gano Dunn, president-elect of the Institute, and vice-president and chief engineer of the Crocker-Wheeler Company, Ampere, N. J. Following the dinner a brief business meeting was held for the election of officers for the ensuing year, resulting as follows: Chairman B. A. Stowe; secretary R. B. Chillas, Jr.; treasurer, F. M. Hibben; board of managers, G. S. Merrill, chairman, Howard Dingle, E. P. Roberts.

Mr. Dunn was then introduced by Chairman Allen, and gave an informal talk on subjects of general engineering interest.

DETROIT-ANN ARBOR

The Detroit-Ann Arbor Section held its last regular meeting for the year at the Wayne Hotel, Detroit, where the members assembled for luncheon at one o'clock. This was followed by a short business meeting, at which a set of by-laws were approved and adopted. All the present officers were re-elected.

The main feature of the meeting was a paper by Mr. J. C. Mock on "The Electrification of the Detroit River Tunnel." Following the paper the party was taken for a ride through the tunnel on one of the electric locomotives and made an inspection of the substation.

MADISON, WIS.

The Madison Section held its regular monthly meeting in the engineering building, University of Wisconsin, on May 24. Mr. J. N. Cadby, electrical engineer with the Wisconsin Railroad Commission, was elected chairman for the year 1911–1912. A paper entitled "European Developments in Prime Movers" was presented by Professor A. G. Christie. The meeting was under the auspices of the local branch of the A. S. M. E.

MINNESOTA

The Minnesota Section held its regular meeting on May 20. The following papers were abstracted and discussed: "Electric Drive in Flour Mills", by H. R. Heim, discussed by W. H. Bovey, P. Thomas, and Charles A. Lang; "Purification of Water by Electricity", by E. T. Sykes, discussed by Professor George D. Shepardson; "Economical Ornamental Street Lighting", by E. D. Jackson, discussed by A. D. Meeds.

PITTSBURG

The Pittsburg Section held its regular monthly meeting on May 9. A paper entitled "The Cost of Arc Lighting and General Service from Small and Medium Sized Power Plants", was read by Mr. W. Edgar Reed, and discussed by Messrs. R. D. Thomas, C. E. Stephens, and H. N. Muller.

PORTLAND, ORE.

The final meeting and second annual dinner of the Portland Section was held on the evening of May 16. The following officers were elected for the ensuing year: Chairman, F. D. Weber; secretary, H. R. Wakeman; executive committee, L. B. Cramer, chairman, W. H. Hamilton, and C. L. Wernicke. Mr. J. B. Frank, of the Pittsfield Section, was among the guests and gave a short talk on how to increase the membership and arrange the meetings and programs.

ST. LOUIS

The annual meeting of the St. Louis Section was held on May 10. The following officers were elected for the ensuing year: Chairman, G. W. Lamke; secretary, F. J. Bullivant; executive committee, the chairman and secretary, and Messrs. J. A. Krauechi, J. H. Brunniga, S. N. Clarkson. Some discussion followed the election of officers

Digitized by Google

in regard to taking further action on Mr. Gutmann's paper on patent law presented at the last meeting. The matter was referred to the executive committee.

WASHINGTON, D. C.

On Sunday, May 21, the Washington and Baltimore Sections, with the co-operation of the Washington Society of Engineers and the Engineers' Club of Baltimore, visited the hydroelectric plant of the Pennsylvania Water and Power Company at Holtwood, near McCall Ferry on the Susquehanna River, about 24 miles above the head of Chesapeake Bay. About 200 engineers and electrical men from the two cities embraced the opportunity offered to visit this large and interesting plant, which is now in operation. The enterprise contemplates ultimately the development of 135,000 horse power by 10 large units. At present four units have been completed, and energy is being transmitted at 70,000 volts, to Baltimore, 40 miles distant. Mr. John Abbet Walls, chief engineer of the company, met the visiting engineers at the railroad station, and assisted by a number of other officers and gentlemen associated with the power company he took the visitors in small groups over the entire plant. The trip was a very interesting one and was much enjoyed by both the Washington and Baltimore delegations.

Past Branch Meetings

ARMOUR INSTITUTE OF TECHNOLOGY

The regular meeting of the Armour Institute Branch was held on May 11. Mr. Frank F. Fowle gave a lecture on "Engineering Specifications." Mr. Fowle emphasized the importance to the engineer of some knowledge of contracts, since specifications usually form parts of contracts. He pointed out, however, that the engineer should not attempt to perform the work of a lawyer, but should coöperate with the lawyer in the performance of his duties as an engineer. After discussing the subject of contracts, the speaker gave his attention to specifications. The general classes into which specifications might be divided were given, and the fundamental principles to be considered in their preparation were fully discussed. It is not possible to lay down rules covering all the details of the preparation of specifications, and the engineer must be governed in these points by judgment and experience. A few examples were given of some good specifications, and in conclusion the speaker gave a list of reference works relating to business law and contracts in general.

A short business meeting was held on May 18 for the election of officers. Mr. L. H. Roller was elected chairman, and Mr. E. H. Freeman was re-elected secretary, for the year 1911–1912.

COLORADO STATE AGRICULTURAL COLLEGE

This Branch held its regular meeting on May 17, and the following papers were presented: "Application of Small Motors to Machine Shop Practice", by A. J. Calloway; "The 100,000 Cycle Generator", by A. E. Johnson.

UNIVERSITY OF COLORADO

The University of Colorado Branch held its regular meeting on May 17. The following officers were elected for the ensuing year: Chairman, L. R. Leonard; vice-president, R. H. Hull; secretary, W. C. Du Vall; treasurer, R. H. Twiss. Mr. P. W. Woolridge, of the Northern Colorado Power Company gave a talk on the "Duties of a Superintendent."

UNIVERSITY OF KANSAS

The University of Kansas Branch held its final meeting for the season on May 17. Officers for the ensuing year were elected as follows: Chairman, L. A. Baldwin; vice-chairman, M. K. Thomen; secretary and treasurer, M. H. Hobbs; executive committee, Professor C. A. Johnson, chairman, R. Parker, S. S. Schooley, J. C. Musselman. Mr.

Digitized by Google

Ray Jones, K. U. '08, then gave a talk on "The Central Colorado 104,000-Volt Transmission System."

Lehigh University, South Bethlehem, Pa.

The Lehigh University Branch held its final meeting for the season on May 9. The election of officers for the ensuing year resulted as follows: Chairman, W. I. Nevins; vice-chairman, R. E. Palle; secretary, G. J. Shurts; treasurer, W. L. Newman; faculty adviser, Professor W. S. Franklin. After the election a paper entitled "The Second Edition of the Electric Journal" was presented by Professor S. S. Seyfert. It was a humorous paper, sparkling with witticisms, and was greatly appreciated by the members present. A second paper, entitled "Electrical Applications to the Steel Industry" was read by Mr. Brent Wiley, of the Westinghouse Electric and Manufacturing Company. Sixty-two members were present at the meeting.

Lewis Institute, Chicago

The Lewis Institute Branch closed its activities for the season at a meeting held on May 26. Mr. Samuel G. McMeen, of McMeen and Miller, gave a talk on "The Electrical Engineer and the West", illustrated with lantern slides showing a number of western engineering installations. Mr. McMeen spoke of the large ratio of square miles to population, which exists in the West, and of the scarcity of manufacturing establishments. He stated that with the development of more hydroelectric plants and the resulting increase in the supply of electric power over and above that which is now demanded for electric lighting and transportation, more factories would be established, which consequently would decrease the abnormal area-population ratio. Mr. McMeen also spoke of the telephone system in San Francisco, and the method of its design and construction. The lecture closed with a description of some of the neighboring hydroelectric stations and of their development. The lecture was preceded by a dinner which was attended by 65 members and their friends. During the course of the evening the following officers were elected for the ensuing year: Chairman, Harry Gilbert; secretary and treasurer, A. H. Fensholt.

University of Maine

The regular meeting of the University of Maine Branch was held on May 25. Mr. J. T. Robinson presented an abstract of the paper on "Railway Telephony", by Gregory Brown, printed in the April Proceedings.

Montana State College

This Branch held its regular meeting on May 5. Mr. V. A. Wolcott, of Butte, Mont., gave a talk on the apprenticeship course of the General Electric Company.

University of Nebraska

A meeting of the University of Nebraska Branch was held on April 8, and the following papers were presented: "Engineering Contracting", by Professor J. N. Bridgman, and "Central Steam Heating", by Mr. O. J. Shaw.

New Hampshire College

The New Hampshire College Branch held its last regular meeting for the season on Monday evening, May 22. The following officers were elected to serve for the coming year: Chairman, L. W. Hitchcock; secretary, L. L. H. Bunker, and the third member of the executive committee, Professor A. F. Nesbit.

University of Michigan

The University of Michigan Branch held its final meeting for the season on June 7. The following officers were elected: Chairman, Walter M. Rennie; secretary and treasurer, La Vern E. Clapp.

Digitized by Google

OHIO STATE UNIVERSITY

The Ohio State University Branch gave an electrical show on May 12 and 13, in the electrical engineering laboratory of the university. The exhibits were of two general types; those entirely due to students, which in general related to special uses of electricity not commonly known, and a group of commercial exhibits supplied by manufacturing and commercial companies. Some of the apparatus on exhibition was shown in operation. The exhibit of telephone apparatus was very complete. The cooking apparatus on exhibition was operated by students of the department of domestic science, and a coal-mining electrically driven coal cutter and drill were installed in a covered pit arranged to represent a coal mine. During the exhibition demonstrations were given of the operation of various devices and processes, including the alternating-current rectifier, high-tension transformer, photometers, electric welding, wireless telegraphy, the talking arc, a wireless control arrangement, Geissler tubes, etc. The exhibits in illumination, both interior and exterior, were very complete.

The regular monthly meeting of the Branch was held on May 23, and the following officers were elected for the coming year: Chairman, C. S. Gordon; secretary and treasurer, C. E. Jennings; corresponding secretary, P. P. Steffan. The treasurer reported that the proceeds of the electrical show were about $175, and it was voted that the money be set aside for educational purposes.

UNIVERSITY OF OREGON

A meeting of this Branch was held on May 31. Professor C. W. Converse gave an illustrated lecture on "The Steam Turbine." Beginning with the steam engine of Hero, (120 B.C.) the speaker traced the history and development of the turbine down to the present time. A number of views were given showing the arrangement of guides and buckets on the different types of turbines.

SYRACUSE UNIVERSITY

The regular monthly meeting of the Syracuse University Branch was held in the College of Applied Science on May 18, Dr. W. P. Graham presiding. Professor J. C. Smallwood discussed the Institute paper by Dickinson and Robinson on "Testing Steam Turbines and Steam Turbine Generators."

THROOP POLYTECHNIC INSTITUTE

The last regular meeting of the Throop Polytechnic Institute Branch was held on May 19. The following officers were elected to serve during the season of 1911–1912: Chairman, R. W. Sorensen; vice-chairman, Walter Newton; secretary, J. D. Merrifield; treasurer, Roy Gerhart. At the close of the executive business Messrs. Hicks, Thornburg and Ben Hayes presented a paper on "The Humphrey Internal Combustion Pump", and demonstrated its efficiency over other forms of pumps.

WORCESTER POLYTECHNIC INSTITUTE

Professor J. H. Hunt, of the Ohio State University, addressed the members of the Worcester Polytechnic Institute Branch at its regular monthly meeting held on May 5. The subject was "Variable Speed Generators." Professor Hunt considered them as sources of energy for illumination and limited their application to vehicles, touching briefly on railway car illumination and going into automobile lighting details. There are three methods of supplying energy to railway carriage lights; namely, by storage batteries charged at stations, by turbo-generators situated on the engine, tender, or baggage car, and by a variable speed generator located on a truck, of each car and operating by a storage battery. The last method seems to be the most satisfactory. In automobile work the conditions are more severe than those of railway work because of the wide and rapid variations. Professor

Digitized by Google

Hunt illustrated the various circuits used in practice, and, in closing, discussed many of the patented systems, some of which are of little practical value.

Following the lecture, officers of the Branch for the year 1911–1912 were elected. These were: Chairman, Charles F. Stearns; vice-chairman, Joseph L. Roberts; secretary and treasurer, Millard F. Clement. In addition to the chairman and the secretary the following were elected members of the executive committee: Professor Joseph O. Phelon, William C. Greenough, Daniel J. Riordan, and William H. Acton.

On May 10 Mr. Francis J. Adams, of the electrical engineering department of the Worcester Polytechnic Institute, gave a lecture on "High Tension Stunts." He performed many experiments employing high potentials. Among these were a comparison of the voltages necessary to break down the same air gap when using different shaped oscillators, an exhibition of corona, blowing out a lighted candle from a discharged point, breaking down insulators and a high tension bushing of considerable capacity. This was the last meeting of the year, and about 425 members were present.

Personal

MR. PARKER H. KEMBLE, until recently with the Brooklyn Edison Company, has been appointed general sales manager of the Toronto Electric Light Company, Toronto, Ont.

MR. J. A. CULVERWELL, of Port Hope, Canada, has been made a life member of the Engineers' Club of Toronto. Mr. Culverwell has been traveling for several months for a rest after completing the organization of his power companies in Central Ontario, on the Trent and Otonabee Rivers.

MR. R. L. NOGGLE has resigned as superintendent for the Northern Idaho and Montana Power Company at Sandpoint, Idaho, to accept the position of superintendent of construction with the Pacific Power and Light Company of Portland, Oregon.. Mr. Noggle's headquarters for the present will be Walla Walla, Wash.

Obituary

MR. H. W. FELLOWS, an Associate of the Institute, died in Portland, Oregon, on May 19, 1911. Mr. Fellows was born in Worcestershire, England, and received his technical education at Mechanics Institute, under the auspices of the South Kensington Science and Art Department, London. Subsequently he came to America and settled in the Northwest. For several years he has been at Spokane and Goldendale, Washington. Mr. Fellows was elected an Associate of the Institute on May 19, 1903.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

L'Academie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique. Anunaire, 1911. Bruxelles, 1911. (Gift of Academie Royale de Belgique).

Autogenous welding by the oxy-acetylene blowpipe. London, 1910. (Purchase.)

Building Construction and Superintendence. By F. E. Kidder. pts. 1–3. New York, 1909–10. (Purchase.)

Canada Commission of Conservation. Agricultural work in Ontario. By C. C. James: Unsanitary Housing. By Chas. A. Hodgetts. (Lectures delivered at the 2d Annual meeting of the Commission of Conservation, January 17, 1911) n.p. n.d. (Gift of Commission of Conservation.)

Congreso Cientifico Internacional Americano. Proceedings Vol. I. Buenos Aires, 1910. (Exchange.)

Electric Railway Dictionary. By Rodney Hitt. New York, McGraw Publishing Co., 1911. (Purchase.)

Digitized by Google

Elektrizität aus Kehricht. By Etienne de Fodor. Budapest, 1911. (Gift of Allgemeinen Elektrizitäts-Gesellschaft).

Foreign and Colonial Patent Laws. By W. C. Fairweather. New York, Van Nostrand, 1910. (Purchase.)

International Catalogue of Scientific Literature. 9th Annual Issue. A-Mathematics. London, 1911. (Gift of E. D. Adams.)

Iowa Engineering Society. Proceedings of the 23d Annual Meeting, 1911. Iowa City, 1911. (Gift of Iowa Engineering Society.)

Municipal franchises. Vol. 2. By D. F. Wilcox. New York, Engineering News Publishing Co., 1911. (Gift of publishers). Price, $5.00 net.

This second volume is of especial interest at the present time, as it deals with transportation franchises and the control of public utilities. It treats very fully of street railway franchises and summarizes the history of recent franchise discussions in the most detailed way. Dr. Wilcox is the chief of the Bureau of Franchises of the Public Service Commission for the First District of New York. W. P. C

National Electric Light Association. Report of committee on overhead line construction. (Technical Session.) New York, 1911. (Exchange)

National Physical Laboratory. Collected Researches. Vol. 7, 1911. Teddington, 1911. (Exchange.)

——Report for the year 1910. Teddington, 1911. (Exchange.)

New York (State) Public Service Commission, 1st District Annual Report, Vols. 1–3, 1909. Albany, 1910. (Exchange.)

Physikalisch Technischen Reichsanstalt. Bekanntmachung uber Prüfungen und Beglaubigungen durch die Elektrischen Prüfämter Nos. 60–63. n.p. n.d. (Exchange.)

Physiologia nova de magnete. n.p. 1628. (Purchase.)

Providence Public Library. Annual Report, 33d, 1910. Providence, 1911. (Gift of Providence Public Library.)

Reibung von elektrizitätszählern mit rotierendem Anker und der einfluss der reibung auf die fehlerkurve. By Karl Schmiedel. N. Berlin, 1911. (Exchange.)

Royal Society of London. Philosophical Transactions. Series B, Vol. 201. London, 1911. (Gift of E. D. Adams.)

Societe Francaise de Physique. Liste de Members, 1911. Paris, 1910. (Exchange.)

Societe Internationale des Electriciens. Annuaire, 1911. Paris, 1911. (Exchange.)

Spon's Workshop Receipts. Vols. 3–4. New York, Spon & Chamberlain, 1909. (Gift of Publishers). Price $1.50 each.

The four volumes of this work are of value in that they give in clear and condensed form description of the various processes in use in the trades, some of this information cannot be found except by prolonged search, and its segregation in these handy volumes should save much time to a busy man. As the work is compiled and published in England, the practice in some cases differs from that in vogue in this country; this is perhaps advantageous for comparison may suggest methods unknown here. W. P. C.

Submarine cables for long distance telephone circuits. By W. A. J. O'Meara. (Reprint from Institution of Electrical Engineers, Proceedings, 1911, pt. 206, Vol. 46). London, 1911. (Exchange.)

Tramways and Light railways (Street and Road) of Great Britain. London, 1910. (Purchase.)

University of Tennessee. Register, 1910–1911. Knoxville, 1911. (Gift of University of Tennessee.)

Westinghouse Electric & Manufacturing Company. Annual Report, March 31, 1911. (Exchange.)

Trade Catalogues

Allgemeine Elektricitats Gesellschaft, Berlin. Modern installation equipment and its safety and convenience factors. 22 pp.

——Transformers, type A T. 8 pp.

——Resistance of iron wires. 8 pp.

——A. E. G. motor generators. 8 pp.

——Turbo-compressors. 18 pp.

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON. LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)

JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)

MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)	(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
DAVID B. RUSHMORE.	A. W. BERRESFORD.	H. H. BARNES, JR.
W. G. CARLTON.	WILLIAM S. MURRAY.	R. G. BLACK.
CHARLES W. STONE.	HENRY H. NORRIS.	W. S. RUGG.
H. E. CLIFFORD.	SEVERN D. SPRONG.	C. E. SCRIBNER.

TREASURER. (Term expires July 31, 1911.) **SECRETARY.**

GEORGE A. HAMILTON. RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884–1910.

*NORVIN GREEN, 1884–5–6.
*FRANKLIN L. POPE, 1886–7.
T. COMMERFORD MARTIN, 1887–8.
EDWARD WESTON, 1888–9.
ELIHU THOMSON, 1889–90.
*WILLIAM A. ANTHONY, 1890–91.
ALEXANDER GRAHAM BELL, 1891–2.
FRANK J. SPRAGUE, 1892–3.
EDWIN J. HOUSTON, 1893–4–5.
LOUIS DUNCAN, 1895–6–7.
FRANCIS B. CROCKER, 1897–8.
A. E. KENNELLY, 1898–1900.
CARL HERING, 1900–1.
CHARLES P. STEINMETZ, 1901–2.
CHARLES F. SCOTT, 1902–3.
BION J. ARNOLD, 1903–4.
JOHN W. LIEB, JR., 1904–5.
SCHUYLER S. WHEELER, 1905–6.
SAMUEL SHELDON, 1906–7.
HENRY GORDON STOTT, 1907–8.
LOUIS A. FERGUSON, 1908–09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

Digitized by Google

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
W. L. MERRILL, Schenectady, N. Y.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

Digitized by Google

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York.
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE P. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
PARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Columbia University, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, Chicago, Ill.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y.
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman
100 Broadway New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS' COMMITTEE.

FRANK J. SPRAGUE, Chairman, 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.

C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.

W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.

JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.

H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.

DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York.
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis.
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N. Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W. STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS B. STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven Conn.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y,
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, PARLEY OSGOOD, Newark, N. J.

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	H. P. Wood.	H. M. Keyes, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor. Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, Wagner Electric Mfg. Co., St. Louis, Mo.
Toledo.....June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto.....Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana.....Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas.....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa
Case School, Cleveland.....Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College.....Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs. University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oregon State Agr. Col Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26–30, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

THE MECHANICAL AND ELECTRIC CHARACTERISTICS OF TRANSMISSION LINES

BY HAROLD PENDER AND H. F. THOMSON

The object of this paper is to present in compact form the data and formulæ, together with their derivations, required for the determination of the mechanical and electric characteristics of transmission lines, together with a set of charts whereby the various mathematical operations involved may be accomplished rapidly and with the minimum effort. The treatment naturally falls under two headings, A—Mechanical Characteristics, and B—Electric Characteristics. Summaries of the working symbols and equations for Part A and Part B follow the general discussion under these heads.

A. Mechanical Characteristics

The following discussion will be limited to the consideration of the characteristics of a perfectly flexible wire suspended from two fixed points of support. Actual wire spans closely approximate this condition, particularly when the successive spans are all of the same length, whether the supporting insulators be of the pin or of the suspension type. In the case of successive spans of unequal length the change in tension in the various spans, due to the variation of temperature and the mechanical load on the wire, will not be the same in each span and consequently such changes will produce a resultant force on the insulator, causing thereby a slight deflection of the top of the tower; or a deflection of the insulator only, if the latter is of the suspension type. This motion of the points of support will tend to equalize the tensions in the various spans.

Note:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

In the design of a wire span two problems must be solved: 1. At what tension (or sag) must the wire be strung in order that the tension in the span may not exceed a definite limit under the worst conditions of temperature and of mechanical loading (due to ice and wind); and 2. What will be the maximum vertical sag of the wire for a given variation in loading and temperature. The factors which enter into these two problems are the following:

1. The length of the span.
2. The material of the wire.
3. The size of the wire.
4. The coefficient of linear expansion of the wire. For copper this coefficient is 9.6×10^{-6} and for aluminum 12.8×10^{-6}, the temperature in each case being expressed in degrees Fahrenheit.
5. The modulus of elasticity of the wire. The modulus of elasticity for copper or aluminum is not strictly a constant, but may be assumed as such as a first approximation. For copper this modulus varies from 12×10^6 to 16×10^6, depending upon the quality of the wire and upon whether the wire is stranded or solid. The former figure is generally used for stranded copper wires. For aluminum wire, which is always stranded when used for transmission lines, the modulus is equal to 9×10^6. The modulus M is equal to the increase of tension ($\triangle T$) in pounds per square inch required to produce an elongation ($\triangle \lambda$) of a given length of wire (λ) divided by the ratio of the elongation to the original length, *i.e.*,

$$M = \triangle T \div \frac{\triangle \lambda}{\lambda} = \lambda \frac{\triangle T}{\triangle \lambda}$$

6. The maximum tension in pounds per square inch to which the wire should be subjected. This maximum allowable tension is usually taken at one-half the ultimate tensile strength of the wire, about 30,000 lb. per sq. in. for copper and 13,000 lb. per sq. in. for aluminum.
7. The maximum external load to which the wire may be subjected due to the collection of sleet on the wire and the pressure of the wind against it. This, of course, will depend upon climatic conditions, but even for a given section of the country, there is considerable difference of opinion as to what should be assumed as a reasonable external load. The Joint Committee on Overhead Line Construction has recently recom-

Digitized by Google

mended that the maximum loading for high tension crossings be taken as that due to an ice coating 0.5-in. thick all around the wire plus a wind pressure of eight lb. per sq. ft. of the projected area of this ice cylinder. To meet this requirement on a long span, especially with aluminum wire, would require a relatively large sag, from 30 to 100 ft., depending on the length of span and size of wire. This would require a prohibitive height of tower, at least for level country work. For cross country spans it would, therefore, seem advisable to assume a less heavy loading, particularly as an ice coating of 0.5-in. and a wind velocity of 60 miles per hr. (corresponding approximately to eight lb. wind pressure) will seldom, if ever, exist simultaneously.

8. The minimum temperature at which the maximum external load occurs. Here again there is considerable difference of opinion, even for given climatic conditions. The Joint Committee on Overhead Line Construction recommends the assumption of a minimum temperature of -20 deg. fahr. for lines situated in the northern part of this country. For cross country spans the assumption of a higher temperature would seem more reasonable, in view of the fact that sleet seldom exists on a wire when the temperature is much below freezing.

9. The temperature at which the wire is to be strung. As an average stringing temperature 70 deg. fahr. is a reasonable assumption.

10. The maximum temperature to which the wire may be subjected. For lines located in the northern part of this country a maximum temperature of 120 deg. fahr. is reasonable. It should be noted that the temperature of a wire exposed to the sun is considerably higher than the temperature of the surrounding air.

The interrelation of these various quantities in the case of a wire suspended from two fixed points of support will be considered in detail.

Determination of the Ratio (K) of the Resultant Force on the Wire to the Weight of the Wire

The total force on a span of wire under any condition of mechanical loading consists in general of three components; 1, its own weight, 2, the weight of the ice coating, and 3, the force acting on it due to wind pressure. It is usual to assume that the wind pressure is horizontal, although it may have a considerable vertical component, particularly if the span is parallel to the

Digitized by Google

base of a steep hill. The other two components of the resultant force on the wire are vertical.

Let w = weight in pounds of one foot of the wire.
d = diameter of wire in inches.
i = thickness of ice coating in inches.
v = wind pressure in pounds per square foot perpendicular to the wire.
K = ratio of total force on the wire to weight of wire under these same conditions.

The vertical force in pounds on one foot length of the wire under a given mechanical load is then

$$w+\frac{57}{144}\cdot\frac{\pi}{4}\cdot(d+2i)^2-d^2=w+1.24\,i\,(d+i)$$

where the weight of ice is taken as 57 lb. per cu. ft. (Tests show that the sleet formed on a wire weighs less than this, due probably to air bubbles in it—this figure is, however, on the safe side.) The horizontal force acting on one foot of the wire is

$$\frac{v}{12}(d+2i)$$

The resultant force acting on one foot of the wire is then

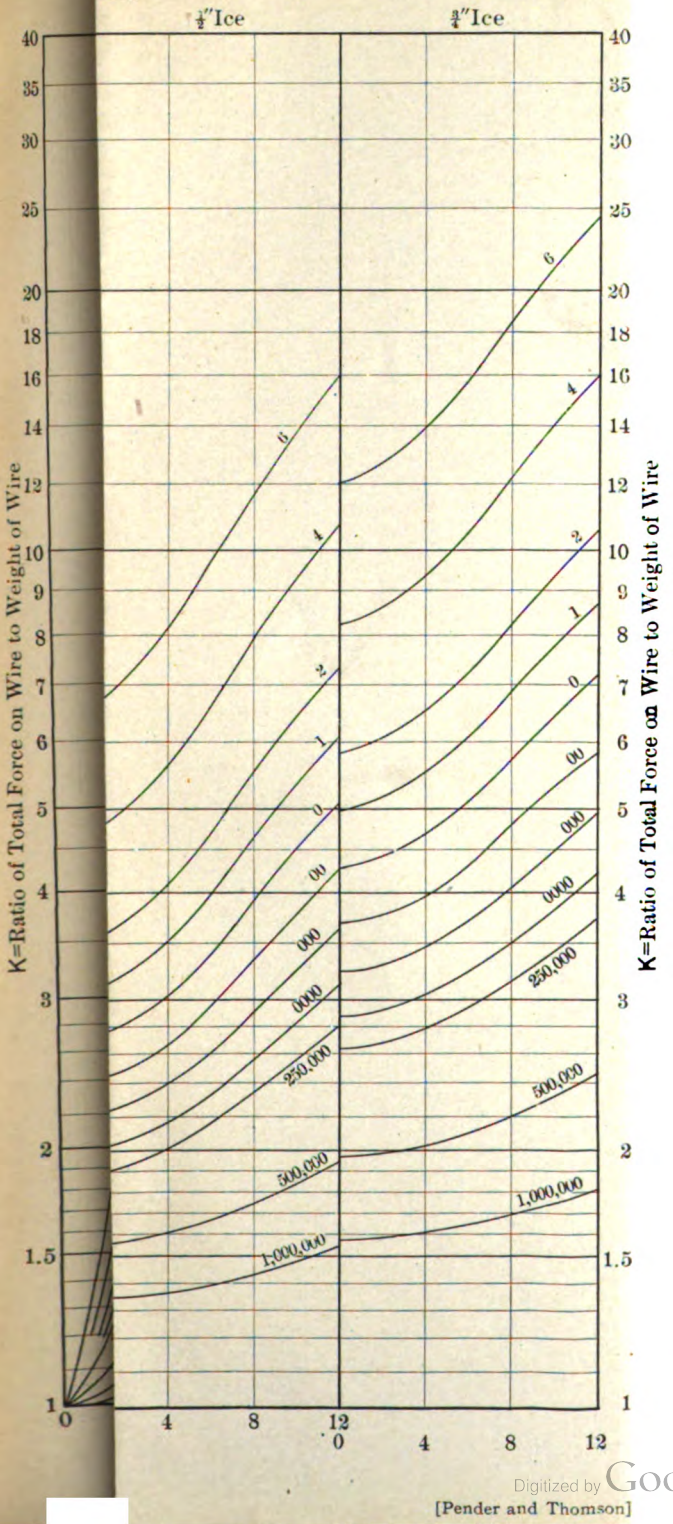
$$\sqrt{\left(w+1.24\,i\,(d+i)\right)^2+\left(\frac{v\,(d+2i)}{12}\right)^2}$$

and therefore the value of the ratio K is

$$K=\sqrt{\left(1+\frac{1.24\,i\,(d+i)}{w}\right)^2+\left(\frac{v\,(d+2i)}{12\,w}\right)^2} \qquad (1)$$

The values of this ratio K for the various sizes of wire between 1,000,000 circular mils and No. 6, B. & S. gauge, for both copper and aluminum, for no ice and for ice thicknesses of $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ in., and for wind pressures from 0 to 12 lb. per sq. ft., are plotted on Chart No. 1. On this chart is also given a short table showing the relation between indicated wind velocity and pressure per square foot. The latter is deduced from the formula given by H. W. Buck in the Transactions of the International Electric

Digitized by Google



[Pender and Thomson]

Digitized by Google

Digitized by Google

Congress, 1904; this formula is that the wind pressure in pounds per square foot of projected area of a round cylinder of diameter d_1 produced by an actual wind velocity of V miles per hour is $0.00021\ V^2\ d_1$.

The Equations of a Wire Span

In the following discussion the wind pressure will be assumed perpendicular to the vertical plane through the two points of support and the pressure per foot of wire in the direction of the wind will be assumed constant at all points irrespective of the angle between the wire and the direction of the wind. This assumption is not strictly realized since the wire near the points of support will make an angle of less than 90 deg. with the direction of the wind, and therefore to obtain an exact solution the wind pressure should be resolved into its two components, one acting in the direction of, and the other perpendicular to, the wind. Since the angle between the wire and the direction of the wire is in general very nearly 90 deg., the assumption that the wind pressure actually exerted on the wire is equal to the pressure which would be exerted were the wire in a vertical plane normal to the wind will not introduce an appreciable error, in comparison with the variations in the wind pressure which will occur due to the actual variation in wind velocity at different parts of the span.

The general case of the points of support at different elevations will also be considered, and the wire will be assumed to lie in a plane through the two points of support parallel to the direction of the resultant force. This assumption is not strictly realized when there exists a combination of wind pressure with the two points of support at different elevations, but is strictly true in all cases when the points of support are at the same elevation, and in the former case gives a solution as nearly correct as can be obtained without an elaborate analysis.

Fig. 1 is a diagram of a span of wire in perspective. This diagram shows the general case when the points of supports are at different elevations and when there is a horizontal component of the force (wind pressure) acting on the wire. Fig. 2 shows only the plane $A\ E\ F\ B$ which is the plane in which the wire lies. When there is no wind this plane is vertical.

The plane $A\ E\ F\ B$ is determined by the line $A\ B$ and the direction of the resultant external force. The planes $A\ E\ R$ and $B\ F\ U$ are determined by the two components of the resultant

Digitized by Google

force. $A\ G$ is drawn in the plane $A\ E\ F\ B$ through A perpendicular to the resultant force. $E\ O\ F$ is drawn in the plane $A\ E\ F\ B$ perpendicular to the resultant force and through the point O where the wire is also perpendicular to the resultant force.

Let f = tension in pounds at any point P of the wire.

α = angle between the tangent to the wire at this point and the line $A\ G$ drawn perpendicular to the resultant external force.

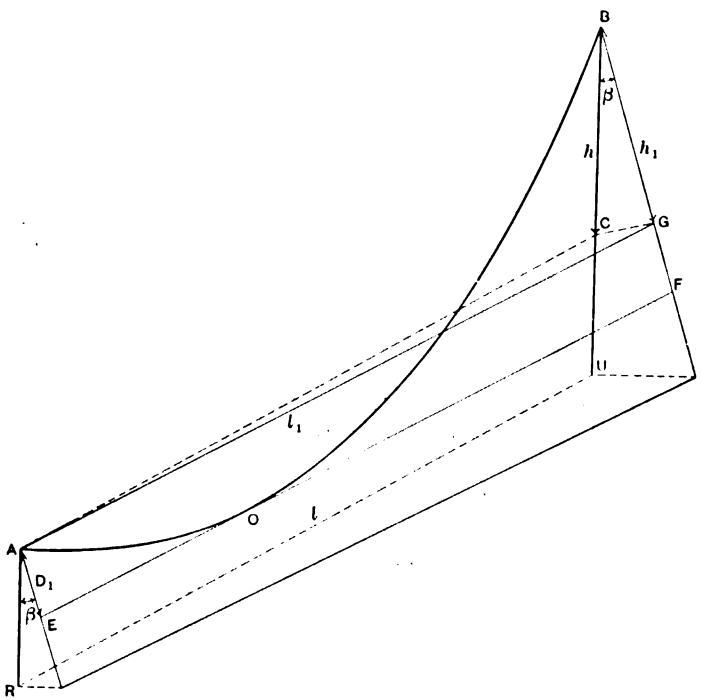


FIG. 1

F = tension in pounds at the point O where the wire is perpendicular to the resultant force.

x = the horizontal distance between the point P and the point O.

y = perpendicular distance from P to the line $O\ X$.

λ = length of wire in feet from O to P.

$d\ \lambda$ = an elementary length of the wire in feet at the point P.

$K\ w$ = resultant force in pounds acting on a one foot length of the wire due to its own weight, the weight of the ice coating and wind pressure.

Digitized by Google

m = weight in pounds of a bar of the conductor material one foot long and one square inch in cross section. (For copper $m=3.85$; for aluminum $m=1.16$).

T = tension in wire in thousands of pounds per square inch at the point O.

Acting on the elementary length $d\lambda$ are three forces in the directions indicated. The resultant of these three forces must be zero. Hence, resolving these forces parallel to OX and OY respectively, we have

$$(f+df)\cos(\alpha+d\alpha)-f\cos\alpha=0$$

$$(f+df)\sin(\alpha+d\alpha)-f\sin\alpha-K\,w\,d\lambda=0$$

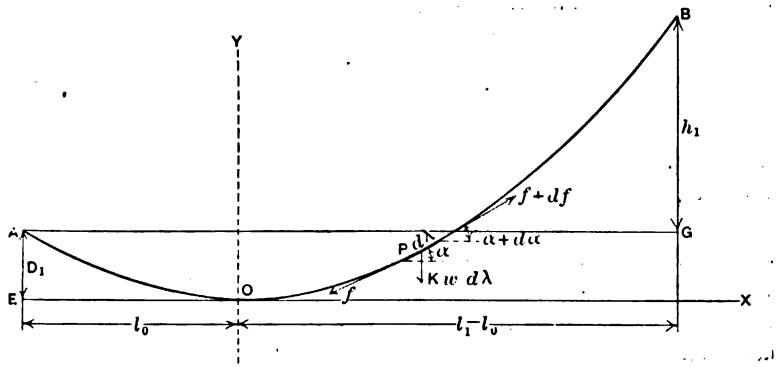


FIG. 2

But since $d\alpha$ is an infinitesimal angle its cosine is unity and its sine is equal to $d\alpha$. Hence,

$$\cos(\alpha+d\alpha)=\cos\alpha-\sin\alpha\,d\alpha$$

$$\sin(\alpha+d\alpha)=\sin\alpha+\cos\alpha\,d\alpha$$

which substituted in the above equations give

$$\cos\alpha\,df-f\sin\alpha\,d\alpha=0$$

$$\sin\alpha\,df+f\cos\alpha\,d\alpha=K\,w\,d\lambda$$

which may in turn be written

$$d(f\cos\alpha)=0 \qquad (2)$$

$$d(f\sin\alpha)=K\,w\,d\lambda \qquad (3)$$

Digitized by Google

Integrating these two equations, we get

$$f \cos \alpha = F \tag{4}$$

and

$$f \sin \alpha = K w \lambda \tag{5}$$

Equation (4) shows that the component of the tension perpendicular to the resultant force is the same at all points of the wire. Equation (5) shows that the component of the tension at any point of the wire in the direction of the resultant force on the wire due to its own weight and external load is equal to the value of this force acting on that portion of the wire between this point and point O at which the wire is perpendicular to the resultant force. The ratio of (5) and (4) gives

$$\tan \alpha = \frac{K w \lambda}{F} \tag{6}$$

This equation involves only the constants K, w and F and the angle α and distance λ; the two latter depend only on the shape of the curve in which the wire hangs. By substituting for α and λ their values in terms of the coördinates x and y, we can obtain the equation of this curve in rectangular coördinates. In (6) substitute $q = \tan \alpha$ and differentiate with respect to x; this gives

$$\frac{dq}{\sqrt{1+q^2}} = \frac{K w}{F} dx$$

The integral of this equation is*

$$q = \sinh \frac{K w x}{F} \tag{7}$$

*For any argument u the hyperbolic sine is

$$\sinh u = \frac{e^u - e^{-u}}{2}$$

and the hyperbolic cosine is

$$\cosh u = \frac{e^u + e^{-u}}{2}$$

Chart No. 5 shows the relation between u, sinh u, and cosh u.

Digitized by Google

Substitute for q its value $\tan \alpha = \frac{dy}{dx}$ and integrate; this gives

$$y = \frac{F}{Kw}\left[\cosh \frac{Kwx}{F} - 1\right] \tag{8}$$

This is the equation of the curve in which the wire hangs; it is the equation of the catenary.

The substitution in (6) of the value of $q = \tan \alpha$ given by (7) gives,

$$\lambda = \frac{F}{Kw} \sinh \frac{Kwx}{F} \tag{9}$$

which is an expression for the length of wire λ from O to the point P in terms of the corresponding distance x measured along the line OX.

Since the weight w of the wire per foot is equal to its cross section multiplied by the weight m of a rod one foot long and one square inch in cross section, and since the tension in pounds F is equal to the cross section of the wire multiplied by 1000 times the tension T in thousands of pounds per square inch,

$$\frac{w}{F} = \frac{m}{1000\,T}$$

Hence equation (8) may be written

$$y = \frac{1000\,T}{Km}\left[\cosh\left(\frac{Kmx}{1000\,T}\right) - 1\right] \tag{10}$$

and equation (9) may be written

$$\lambda = \frac{1000\,T}{Km} \sinh\left(\frac{Kmx}{1000\,T}\right) \tag{11}$$

The hyperbolic cosine of an argument u may be expanded into the series

$$\cosh u = 1 + \frac{u^2}{2!} + \frac{u^4}{4!} + \frac{u^6}{6!} + \cdots\cdots$$

Digitized by Google

and the hyperbolic sine into the series

$$\sinh u = u + \frac{u^3}{3!} + \frac{u^5}{5!} + \frac{u^7}{7!} + \ldots\ldots\ldots$$

Therefore,

$$\cosh u - 1 = \frac{u^2}{2}\left(1 + \frac{u^2}{12} + \frac{u^4}{360} + \ldots\ldots\ldots\right)$$

$$\sinh u = u\left(1 + \frac{u^2}{6} + \frac{u^4}{120} + \ldots\ldots\ldots\right)$$

Hence, for $u < 0.48$, we may write with an error of less than 2 per cent,

$$\cosh u - 1 = \frac{u^2}{2}$$

Also, with an error of less than 0.05 per cent,

$$\sinh u = u\left(1 + \frac{u^2}{6}\right)$$

Hence for

$$K\,m\,x < 480\,T \qquad (12)$$

equation (**10**) may be written, with an error of less than 2 per cent

$$y = \frac{K\,m\,x^2}{2000\,T} \qquad (13)$$

which is the equation of a parabola. In all practical cases, except for extreme conditions of loading or for very long spans, the condition (**12**) is satisfied, and therefore for practical work the equation of a span of wire may be represented with sufficient accuracy by the parabola (**13**).

Under the same conditions, equation (**11**) for the length of wire between O and P may be written with an error of less than 0.05 per cent,

$$\lambda = x\left[1 + \tfrac{1}{6}\left(\frac{K\,m\,x}{1000\,T}\right)^2\right]$$

Digitized by Google

But from (13)

$$\frac{K\,m\,x}{1000\,T}=\frac{2\,y}{x}$$

Therefore, to the same degree of accuracy

$$\lambda=x+\tfrac{2}{3}\,\frac{y^2}{x} \qquad (14)$$

DEFLECTION AND SAG.

From the above equations the deflection and vertical sag of the wire for a given tension T and loading factor K may be deduced readily. In addition to the above symbols, let (see Figs. 1 and 2)

l = length of span in feet; *i.e.*, the horizontal distance between the points of support.

l_1 = distance $A\,G$ in feet.

l_0 = distance $E\,O$ in feet.

D = deflection in feet of the point O from the horizontal line through the two points of support when *with points of support on the same level.*

$p=\frac{100\,D}{l}$ = percentage deflection when *points of support are on the same level.*

K' = ratio of vertical component of external force to weight of wire (K' is the value of K when there is no wind).

$S=\frac{K'\,D}{K}$ = vertical sag corresponding to the deflection D.

h = difference in elevation in feet between the two points of support.

h_1 = the distance $B\,G$.

D_1 = deflection in feet of the point O from the line $A\,G$ (Figs. 1 and 2.)

S_1 = vertical sag in feet corresponding to the deflection D_1.

From equation (13) and Fig. 2,

$$y_a=D_1=\frac{K\,m\,l_0^2}{2000\,T} \qquad (15)$$

and

$$y_b=D_1+h_1=\frac{K\,m\,(l_1-l_0)}{2000\,T} \qquad (15a)$$

Digitized by Google

Subtracting we get

$$h_1 = \frac{K\,m}{2000\,T}\,(l_1^2 - 2\,l_1\,l_0)$$

or

$$l_0 = \frac{l_1}{2}\left[1 - \frac{2000\,T\,h_1}{K\,m\,l_1^2}\right] \qquad (16)$$

The relations between l_1 and l and between h_1 and h may be deduced from Fig. 1. The plane $B\,C\,G$ is perpendicular to $A\,C$ and therefore perpendicular to the plane $A\,C\,G$. Also the angle $B\,G\,A$ is a right angle. Hence the angle $B\,G\,C$ is a right angle. Therefore,

$$h_1 = h\cos\beta = \frac{K_1\,h}{K}$$

Also, $A\,C$ is perpendicular to $G\,C$, since $A\,C$ is perpendicular to the plane $B\,G\,U$; therefore

$$l_1 = \sqrt{l^2 + h^2\sin^2\beta} = l\,\sqrt{1 + \left(\frac{h\sin\beta}{l}\right)^2}$$

The ratio of h to l in any practical case will not exceed 0.25 and the angle β will not exceed 45. Hence l_1 will differ from l by less than 2 per cent. As a first approximation then we may write equation (**16**)

$$l_0 = \frac{l}{2}\left[1 - \frac{2000\,T\,K'\,h}{K^2\,m\,l^2}\right] \qquad (16a)$$

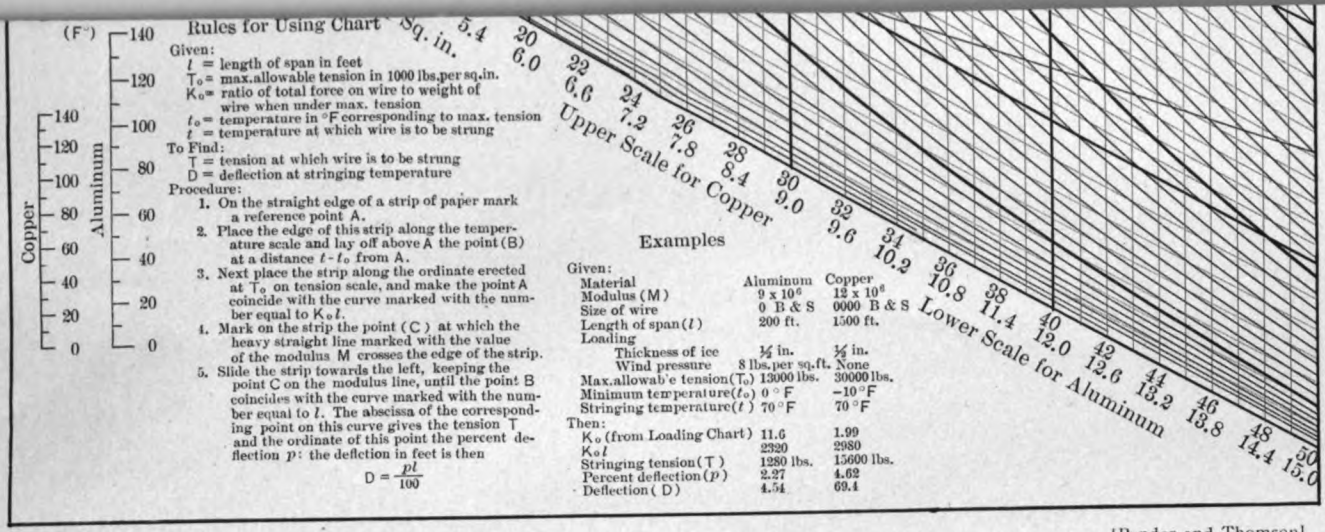
For $h = 0$, that is for the points of support on the same level, $l_0 = \frac{l}{2}$; the point O is then at the center of the span. Hence for *points of support at the same level*,

$$D = \frac{K\,m\,l^2}{8000\,T} \qquad (17)$$

The percentage deflection is then

$$p = \frac{K\,m\,l}{80\,T} \qquad (18)$$

Digitized by Google



Rules for Using Chart

Given:

l = length of span in feet
T_o = max. allowable tension in 1000 lbs. per sq. in.
K_o = ratio of total force on wire to weight of wire when under max. tension
t_o = temperature in °F corresponding to max. tension
t = temperature at which wire is to be strung

To Find:

T = tension at which wire is to be strung
D = deflection at stringing temperature

Procedure:

1. On the straight edge of a strip of paper mark a reference point A.
2. Place the edge of this strip along the temperature scale and lay off above A the point (B) at a distance $t - t_o$ from A.
3. Next place the strip along the ordinate erected at T_o on tension scale, and make the point A coincide with the curve marked with the number equal to $K_o l$.
4. Mark on the strip the point (C) at which the heavy straight line marked with the value of the modulus M crosses the edge of the strip.
5. Slide the strip towards the left, keeping the point C on the modulus line, until the point B coincides with the curve marked with the number equal to l. The abscissa of the corresponding point on this curve gives the tension T and the ordinate of this point the percent deflection p: the deflection in feet is then

$$D = \frac{pl}{100}$$

Examples

Given:	Aluminum	Copper
Material		
Modulus (M)	9×10^6	12×10^6
Size of wire	0 B & S	0000 B & S
Length of span (l)	200 ft.	1500 ft.
Loading		
Thickness of ice	½ in.	½ in.
Wind pressure	8 lbs. per sq. ft.	None
Max. allowable tension (T_o)	13000 lbs.	30000 lbs.
Minimum temperature (t_o)	0 °F	−10 °F
Stringing temperature (t)	70 °F	70 °F
Then:		
K_o (from Loading Chart)	11.6	1.99
$K_o l$	2320	2980
Stringing tension (T)	1280 lbs.	15600 lbs.
Percent deflection (p)	2.27	4.62
Deflection (D)	4.54	69.4

[Pender and Thomson]

Digitized by Google

Chart N
copper a
are like
to *D* is

For a
17 tha

D is t
same ten
the same

and the

'An ins
slightly l
From e
to the lo

This mea

span; i.e.,
to the hi
Since the
wire betw
will be a
If this
on the o

Digitized by Google

Chart No. 2 gives the value of this percentage deflection for both copper and aluminum for the various values of $(K\,l)$ and T which are likely to arise in practice. The vertical sag corresponding to D is

$$S = \frac{K'\,D}{K}$$

For a *difference of elevation* h we then have from (**16***a*) and (**17**) that

$$l_0 = \frac{l}{2}\left[1 - \frac{K'\,h}{4\,K\,D}\right] \qquad (19)$$

D is the deflection corresponding to the same length of span, same tension, and same loading *but the two points of support at the same elevation.* Substituting (**19**) in (**15**) gives

$$D_1 = D\left(1 - \frac{K'\,h}{4\,K\,D}\right)^2 \qquad (20)$$

and the vertical sag corresponding to D_1 will not exceed

$$S_1 = \frac{K'\,D_1}{K} \qquad (21)$$

(An inspection of Fig. 1 will show that the vertical sag may be slightly less than this; formula (**21**) however is on the safe side.)

From equation (**19**) it is seen that the distance of the point O to the lower point of support becomes negative when

$$h < \frac{4\,K\,D}{K'}$$

This means that when $h < \frac{4\,K\,D}{K'}$ the point O lies outside of the span; *i.e.*, the wire has a continuous upward slope from the lower to the higher support. This condition is illustrated in Fig. 3. Since the vertical force downward on the insulator due to the wire between A and B is equal to $K'\,w\,l_0$, if l_0 is negative there will be an upward pull at A.

If this force is greater than the downward pull due to the span on the other side of this support, the resultant force on the

Digitized by Google

insulator will be upward. In laying out a line this condition should of course be avoided by relocating the poles.

When the point O coincides with the lower point of support, $l_0 = 0$, and the horizontal distance between O and the higher point of support is equal to the length of the span l. Hence the greatest value of $\frac{K m x}{1000 T}$ (see equations **10** and **12**) for any point in the span is equal to $\frac{K m l}{1000 T}$, and this in turn is equal to $\frac{8 p}{100}$ where p is the per cent deflection which would be produced by the same tension and loading were the points of support on

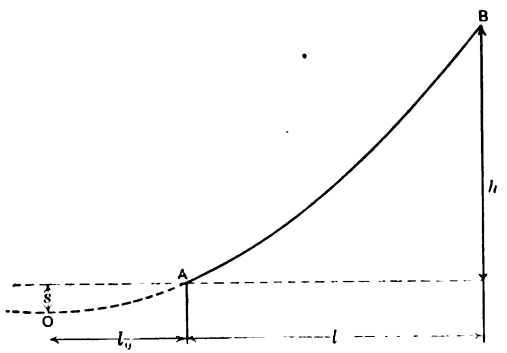


FIG. 3

the same level (see equation **18**). Hence the condition that the approximate equations (**13**) and (**14**) may be applied is that

$$p < 6 \text{ per cent} \qquad (21)$$

Hence the maximum error which can arise from the use of Chart No. 2 for the determination of deflection and sag is less than 2 per cent.

EFFECT OF VARIATIONS IN TEMPERATURE AND MECHANICAL LOADING

We wish next to determine how the tension and deflection of a span of wire varies when the temperature of the wire changes and when the mechanical load on the wire changes (due to the formation or melting of the sleet and changes in wind pressure.) We shall assume that the points of support remain rigidly fixed.

Digitized by Google

Let

t = temperature in degrees fahrenheit under any given set of conditions.

T = tension at O in thousands of pounds per square inch under these same conditions.

K = ratio of resultant force on wire to weight of wire under these same conditions.

K' = ratio of vertical component of resultant force to weight of wire under these same conditions.

λ_1 = length of the wire in feet under these same conditions.

t_0, T_0, K_0, K_0', λ_0 designate the same quantities for any other set of conditions.

a = coefficient of linear expansion of the wire per degree fahrenheit.

M = modulus of elasticity of the wire in (pounds per square inch) units.

Other symbols as above.

From equations (**14**) and (**15**) and Figs. 1 and 2 we have that the length of the wire in the span under any conditions of temperature and loading is

$$\lambda_1 = l_0 + \tfrac{2}{3}\frac{D_1^2}{l_0} + l - l_0 + \tfrac{2}{3}\frac{(D_1+h_1)^2}{l-l_0}$$

$$= l + \tfrac{2}{3}\left(\frac{K\,m}{2000\,T}\right)^2 [l_0^3 + (l-l_0)^3]$$

$$= l + \tfrac{2}{3}\left(\frac{K\,m}{2000\,T}\right)^2 [l^3 - 3\,l\,l_0\,(l-l_0)]$$

From equation (**16***a*)

$$l_0 = \frac{l}{2}\left[1 - \frac{2000\,T\,h\,K'}{K^2\,m\,l^2}\right]$$

$$l - l_0 = \frac{l}{2}\left[1 + \frac{2000\,T\,h\,K'}{K^2\,m\,l^2}\right]$$

whence

$$\lambda_1 = l + \tfrac{2}{3}\left(\frac{K\,m}{2000\,T}\right)^2 l^3\left[\tfrac{1}{4} + \tfrac{3}{4}\left(\frac{2000\,T\,h\,K'}{K^2\,m\,l^2}\right)^2\right]$$

Digitized by Google

or

$$\lambda_1 = l\left[1+\tfrac{1}{6}\left(\frac{K\,m\,l}{2000\,T}\right)^2+\tfrac{1}{2}\left(\frac{K'\,h}{K\,l}\right)^2\right]$$

From (**18**)

$$\frac{K\,m\,l}{2000\,T}=\frac{p}{25}$$

where p is the per cent deflection for the same condition of temperature, loading and tension but for points of support on the same level. Hence the expression for λ_1 may be written

$$\lambda_1 = l\left[1+\frac{p^2}{3750}+\tfrac{1}{2}\left(\frac{K'\,h}{K\,l}\right)^2\right] \qquad (22)$$

Similarly, for any other conditions of temperature and loading the length of the wire is

$$\lambda_0 = l\left[1+\frac{p_0^2}{3750}+\tfrac{1}{2}\left(\frac{K_0'\,h}{K_0\,l}\right)^2\right]$$

Hence the change of length due to the change in temperature and loading is

$$\lambda_1-\lambda_0 = l\left[\frac{p^2-p_0^2}{3750}+\tfrac{1}{2}\left(\frac{K'\,h}{K\,l}\right)^2-\tfrac{1}{2}\left(\frac{K_0'\,h}{K_0\,l}\right)^2\right] \qquad (23)$$

If the points of support remain fixed this change of length can result only from a stretching (or contraction) of the wire due to change in tension and to an expansion (or contraction) of the wire due to change in temperature. This change in length may therefore, also be expressed in terms of the temperature coefficient a, the difference of temperature $t-t_0$, the modulus of elasticity M, and the change in the resultant tension in the wire.

The resultant tension in the wire at any point a distance λ measured along the wire from the point O is equal to

$$T' = \sqrt{f_0^2+(K\,w\,\lambda)^2} = T\sqrt{1+\left(\frac{K\,m\,\lambda}{1000\,T}\right)^2}$$

see equations (**4**) and (**5**).

Digitized by Google

The maximum value of T' for a given value of T will occur at the higher point of support, *i.e.*, for

$$\lambda = l - l_0 = \frac{l}{2}\left[1 + \frac{K' h}{4 K D}\right]$$

see Fig. 1 and equation (**19**). Also, from equation (**18**)

$$\frac{K m l}{2000 T} = \frac{p}{25}$$

whence the maximum value of T' is

$$T' = T\sqrt{1 + \frac{p^2}{625}\left(1 + \frac{K' h}{4 K D}\right)^2} \qquad (24)$$

The maximum value of p likely to arise in practice is 6 per cent, and the maximum value of h is $\frac{4 K D}{K}$ (lowest point of the wire coinciding with lower point of support), and hence the maximum value of T' likely to arise in practice is

$$T' = 1.11\ T$$

The limiting case of a 6 per cent deflection rarely occurs, and even in this case the resultant tension is equal to the higher value, 1.11 T only at the higher point of support; for the greater part of the length of the wire the resultant tension is sensibly equal to the tension T at the point O. Hence in calculating the stretching of the wire by the resultant tension we may take, as a close approximation, the resultant tension at every point equal to the tension at O.

The change in length due to a change of temperature from t_0 to t is

$$a\ (t - t_0)\ \lambda_1$$

and the change in length due to a change in tension from T_0 to T is

$$\frac{1000\ (T - T_0)\ \lambda_1\ [1 + a\ (t - t_0)]}{M}$$

But since the coefficient of expansion a is a very small quantity (of the order of 10^{-5}) the term $a\ (t - t_0)$ may be neglected in

Digitized by Google

comparison with unity for any value of $t-t_0$ likely to arise in practice ($t-t_0$ will never be greater than 150 deg. fahr.). Hence the total change in length ($\lambda_1-\lambda_0$) may be written

$$\lambda_1-\lambda_0=\left[a\,(t-t_0)+\frac{1000\,(T-T_0)}{M}\right]\lambda_1$$

Again, for $p<6$ per cent, λ_1 will differ from l by less than one per cent (see equation **23**); hence with an error of less than one per cent,

$$\lambda_1-\lambda_0=\left[a\,(t-t_0)+\frac{1000\,(T-T_0)}{M}\right]l \qquad (\mathbf{25})$$

Equating (**23**) and (**25**) we have

$$\left(p^2-\frac{3.75\times10^6\,T}{M}\right)-\left(p_0^2-\frac{3.75\times10^6\,T_0}{M}\right)=$$

$$3750\,a\left\{(t-t_0)-\frac{h^2}{2\,a\,l^2}\left[\left(\frac{K'}{K}\right)^2-\left(\frac{K'_0}{K_0}\right)^2\right]\right\} \qquad (\mathbf{26})$$

For the points of support on the same level ($h=0$) or for no change in the position of the plane of the span ($\frac{K_0'}{K_0}=\frac{K'}{K}$; a particular instance of which is no wind pressure, in which case the plane of the span remains vertical), this equation reduces to

$$\left(p^2-\frac{3.75\times10^6\,T}{M}\right)-\left(p_0^2-\frac{3.75\times10^6\,T_0}{M}\right)=3750\,a\,(t-t_0) \qquad (\mathbf{27})$$

Hence, when the tension T_0 at temperature t_0 and the loading factor K_0 are known, the tension T at any other temperature t and loading factor K may be determined by solving this equation for T, after substituting for p and p_0 their values

$$p=\frac{K\,m\,l}{80\,T} \quad \text{and} \quad p_0=\frac{K_0\,m\,l}{80\,T_0}$$

This equation, however, is a cubic in T, and its solution by algebraic methods is extremely difficult. By making use of chart

Digitized by Google

No. 2, however, its solution may be obtained without any arithmetical computations whatever other than a simple multiplication.

The curved lines on this chart give p^2 as ordinates (actual vertical distances equal p^2; the scale on the left of the chart gives p, which is the square root of the vertical distances) against T as abscissas. The numbers on the curves give the corresponding value of $(K\,l)$. Two scales for the tension T are given, one for copper and one for aluminum, this arrangement making possible the use of the same set of curves for both materials. The three heavy straight lines at the base of the chart are drawn so that the ordinate (actual distance) of any point on any one of these lines is equal to

$$\frac{3.75\times 10^6\ T}{M}$$

where T is the abscissa of this point on the proper tension scale and M is the modulus of elasticity of the wire.

The small vertical scales in the lower left hand corner of the chart marked " Temperature Correction " are laid off so that the vertical distance between any two temperature markes t and t_0 is equal to

$$3750\ a\ (t-t_0)$$

SUMMARY

The method of solving equation (**27**) by means of Chart No. 2 is given below. First, however, a summary of the working symbols will be convenient:

l = length of span in feet.

h = difference in elevation of points of support in feet.

T_0 = the tension at the point O (Figs. 1 and 2) in thousands of pounds per square inch under any given condition of temperature and loading.

t_0 = temperature in degrees fahrenheit when the tension is T_0.

K_0 = ratio of resultant force due to weight of wire, weight of ice and wind pressure, to weight of wire (chart No. 1) when the tension is T_0.

K_0' = ratio of the vertical component of this force to weight of wire when the tension is T (K'_0 = value of K from chart No. 1 corresponding to the given size of wire and the given thickness of ice, but no wind.)

Digitized by Google

T = tension in thousands of pounds per square inch for any other condition of temperature and loading.

t = temperature in degrees fahrenheit when the tension is T.

K = ratio of resultant force due to weight of wire, weight of ice and wind pressure, to weight of wire when the tension is T. (For no ice and no wind $K=1$.)

K' = ratio of the vertical component of this force to weight of wire when tension is T. (For no ice and no wind $K'=1$).

D = deflection in feet of the lowest point of the wire from the line through the points of support when the tension is T and the points of support are on the same level. D is measured in the plane of the curve in which the wire hangs.

$p=\frac{100\,D}{l}$ = per cent deflection corresponding to D.

S = vertical sag in feet of the lowest point of wire below the points of support when the tension is T and the points of support are on the same level.

D_1 = deflection in feet of the point O from the line $A\,G$ (see Figs. 1 and 2) when the tension is T and the points of support are not on the same level. (For $h=\frac{4\,K\,D}{K'}$ the lower point of support is the lowest point of the wire.

S_1 = vertical sag in feet of the lowest point of the wire below the lower point of support.

a = temperature coefficient of wire when temperature is expressed in degrees fahrenheit (for copper $a=9.6\times10^{-6}$, for aluminum $a=12.8\times10^{-6}$).

To find the tension T and the corresponding deflection and sag when l, h, T_0, t_0, K_0, K_0', t, K and K' are given, chart No. 2 is used as follows when $\frac{K'}{K}=\frac{K_0'}{K_0}$:

1. On a straight strip of paper mark a reference point A and vertically above this point mark a second point B such that the distance $A\,B$ is equal to $t-t_0$ measured on the temperature scale.

2. Next place the strip of paper with its edge along the ordinate passing through the tension T_0 and make the point A coincide

Digitized by Google

with the intersection of the edge of the strip and the curve marked with the number equal to $(K_0 l)$. Mark on the strip the point C where the heavy straight line marked with the proper modulus M intersects the edge of the strip.

3. Keep the strip of paper vertical and slide the point C along the modulus line until the edge of the strip at B intersects the curve marked with the number equal to $(K l)$. The abscissa of the point B is then equal to the tension T corresponding to the temperature t and loading factor K.

The ordinate of the point B (read on the vertical scale on the left) is the per cent deflection p corresponding to this tension T and loading factor K when the points of support are on the same level. Then the corresponding deflection in feet is

$$D = \frac{p\,l}{100} \tag{28}$$

and the vertical sag is

$$S = \frac{K'\,D}{K} \tag{29}$$

If the difference in elevation of the two points of support is h, the deflection of the lowest point of the wire is

$$D_1 = D\left(1 - \frac{h\,K'}{4\,K\,D}\right)^2 \tag{30}$$

and the vertical deflection is

$$S_1 = S\left(1 - \frac{h\,K'}{4\,K\,D}\right)^2 \tag{31}$$

The deflection and sag corresponding to T_0 are calculated in exactly the same manner from the per cent deflection p_0 corresponding to the tension T_0 and the loading factor K_0; whether the sag corresponding to T will be greater than that corresponding to T_0 will depend upon the temperatures and loading factors.

In case the points of support are not on the same level and there is a change in the direction of the plane of the wire, (*i.e.*,

Digitized by Google

$\frac{K'}{K} \neq \frac{K_0'}{K_0}$), the new tension T must be found by solving equation (**26**). This can also be done by means of Chart No. 2, for the term

$$-\frac{h}{2\,a\,l^2}\left[\left(\frac{K'}{K}\right)^2-\left(\frac{K_0'}{K_0}\right)^2\right]$$

is equivalent to a decrease of temperature numerically equal to this expression. Hence the only change in the procedure described above is to consider the temperature rise not as $t-t_0$, but as

$$t-t_0-\frac{h^2}{2\,a\,l^2}\left[\left(\frac{K'}{K}\right)^2-\left(\frac{K_0'}{K_0}\right)^2\right]$$

The rest of the procedure is exactly the same as before. This correction due to the difference between $\frac{K'}{K_0}$ and $\frac{K'}{K}$ may be important, particularly in passing from the condition of no ice and no wind to the condition of ice and wind, for in the latter case $\left(\frac{K_0'}{K_0}\right)^2$ may be as great as $\frac{1}{2}$ (45 deg. deflection of the plane of the wire from the vertical) whereas for the former $\frac{K'}{K}=1$. Similarly, in the reverse problem of passing from the condition of ice and wind to the condition of no ice and no wind there will be a like correction but the formula without this correction factor will give results on the safe side.

It should also be noted that the maximum resultant tension in the span under any condition of temperature and loading is not equal to the tension T at the point O but in general is equal to

$$T'=T\sqrt{1+\frac{p^2}{625}\left(1+\frac{h\,K'}{4\,K\,D}\right)^2} \qquad (33)$$

(see equation **24**). Similarly, the maximum resultant tension under the "zero" conditions is

$$T_0'=T_0\sqrt{1+\frac{p_0^2}{625}\left(1+\frac{h\,K_0'}{4\,K_0\,D_0}\right)^2} \qquad (33a)$$

Digitized by Google

B. Electric Characteristics

When a given amount of electric power is transmitted over a transmission line to a substation or other receiver, a certain amount of power is lost in the line. There is in general a difference in the voltage between wires at the two ends of the line, and the power factor at the sending and receiving ends will be different. The power loss, voltage loss, and change in power factor in general depend upon the following factors:

1. The amount of power delivered.
2. The voltage at which the power is delivered.
3. The power factor at the receiving end.
4. The frequency of the system.
5. The kind of line—three-phase or single-phase.
6. The length of the line.
7. The size of the wires.
8. The material of the wires.
9. The temperature of the wires.
10. The arrangement of the wires on the poles; particularly their distance apart.

The interrelation of these various factors will be considered in detail.

Resistance, Reactance and Capacity, Susceptance and Leakage

For wires of the size ordinarily used in practice and for any frequency up to 60 cycles, the resistance of a solid wire per unit length depends solely upon the material of the wire and its cross section. A stranded cable has a slightly greater resistance than a solid wire, due to the spiralling of the individual wires which made up the cable. In the table on Chart No. 3 are given the resistance and weight per mile of both copper and aluminum for the various sizes between a No. 16 and 1,000,000 circular mils. This table is calculated for a temperature of 20 deg. cent. (=68 deg. fahr.), assuming a temperature coefficient of 0.42 per cent per degree centigrade; the conductivity of copper is taken as 98 per cent and the conductivity of aluminum as 62 per cent of Matthiessen's Standard; and the resistance and the weight of the stranded wires are taken one per cent greater than for solid wire of the same cross section.

The reactance of a wire in ohms is equal to $2\pi f L \times 10^{-3}$, where f is the frequency and L the self-induction in millihenries. The self-induction of a round solid wire of radius a inches when

Digitized by Google

the return wire is parallel to it and at a distance D inches from it (center to center) is

$$L = 0.7411 \log_{10} \frac{D}{a} + 0.0805 \text{ millihenries per mile.}$$

This formula applies also when the return circuit consists of two wires each of which is at a distance D from the wire in question; that is, the above formula gives the inductance per mile of *each* wire whether the system is single-phase or three-phase, provided in the latter case the wires are arranged symmetrically (*i.e.*, form the three edges of an equilateral prism). The inductance of a stranded wire is practically equal to that of a solid wire of the same cross section of conducting material; for a given number on the B. & S. gauge or for a given area in circular mils the inductance is therefore independent of whether the wire is solid or stranded.

The value of the inductance per mile of wire for various sizes of wire and for various spacings is given on Chart No. 3. This particular form of chart arises from the fact that the inductance depends only upon the *ratio* $\frac{D}{a}$; consequently, all combinations of sizes and spacings for which this ratio is constant give the same value of the inductance. The reactance for both 25 and 60 cycles is also given on Chart No. 3.

The capacity susceptance of a wire in ohms is equal to $2\pi f C \times 10^{-6}$, where f is the frequency and C the capacity in microfarads of the wire to neutral; the susceptance of a wire is the ratio of the charging current to the volts to neutral. The capacity to neutral of a round wire of radius a inches when the return wire is parallel to it and at a distance D inches from it (center to center) is

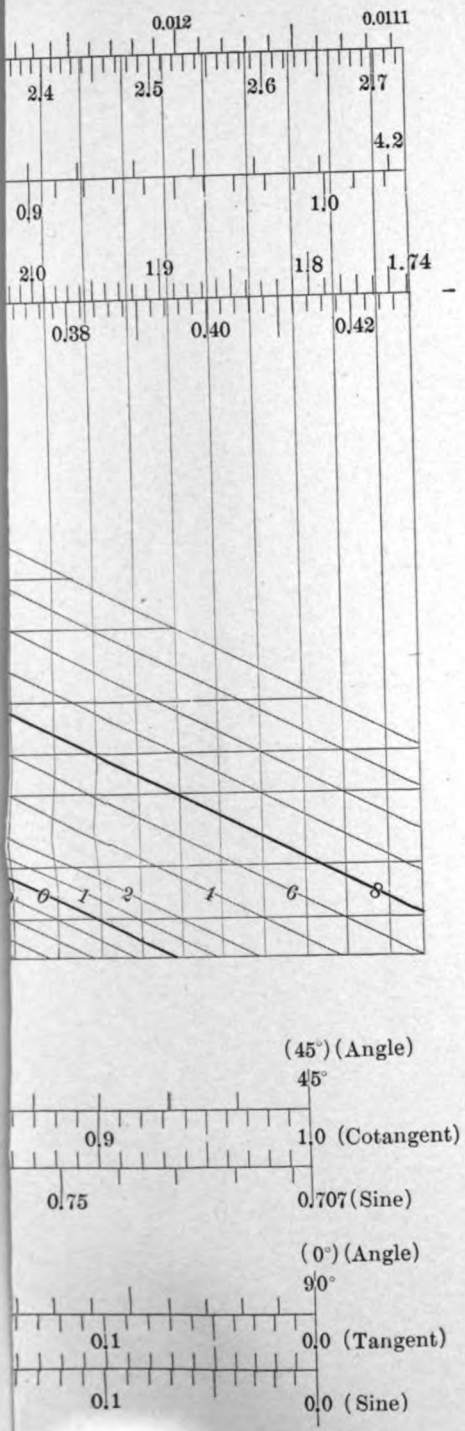
$$C = \frac{0.03883}{\log_{10} \frac{D}{a}} \text{ microfarads per mile,}$$

provided $\frac{D}{a}$ is greater than 12* and the distance from the wire

*When $\frac{D}{a} < 12$, the exact formula for the capacity, when the two wires are at a great distance from all other conductors, is

$$C = \frac{0.08941}{\cosh^{-1} \frac{D}{2a}}$$

Digitized by Google



[Pender and Thomson]

Digitized by Google

Digitized by Google

to all other conductors is large compared with D. This formula applies also when the return conductor consists of two wires each of which is at a distance D from the wire in question. That is, the above formula gives the capacity per mile of *each* wire whether the system is single phase or three phase, provided the wires are at a great distance, compared with D, from all other conductors (*i.e.*, overhead lines) and provided that in the case of a three-phase system the wires are arranged symmetrically (*i.e.*, from the three edges of an equilateral prism.) The capacity of a stranded wire is greater than that of a solid wire, since its radius is greater. The above formula is not strictly applicable to a stranded wire since the latter is not round, but as a first approximation it may be used.

In Chart No. 3 is given the capacity of the various sizes of wire on various spacings. In calculating the capacity scale the

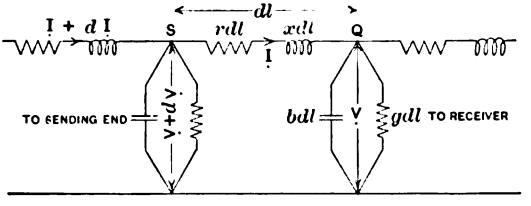


FIG. 4

diameter of the wire in each case was taken 15 per cent greater than the diameter of a solid wire of the same cross section; the ratio of the diameter of a stranded wire to a solid wire is approximately 1.15. The proper correction to obtain the capacity of a solid wire is indicated on the chart. The chart also gives the capacity susceptance at 25 and 60 cycles.

The leakage current between wires under ordinary working conditions is negligible. The leakage need be taken into account only in the case the voltage is sufficiently high to produce the so-called "corona effect". This effect appears only when extra high voltages are used and the wires are comparatively small.

THE EQUATIONS OF A TRANSMISSION LINE.

Fig. 4 is a diagrammatic representation of a section of a transmission line. Each wire of the line, whether single or three phase, may be considered separately and the return for each wire may be represented by a fictitious neutral of zero resistance and zero reactance. Let

Digitized by Google

P = average watts transmitted past the point Q by all of the wires.

E = effective volts between wires at any point Q.

V = effective volts between any one of the line wires and neutral at the point Q. (For a single phase line $V=\frac{E}{2}$; for a three phase line $V=\frac{E}{\sqrt{3}}$)

φ = power factor angle at Q (φ taken positive for lagging current).

I = effective amperes at the point Q. (For a single phase line $I=\frac{P}{E\cos\varphi}$; for a three phase line $I=\frac{P}{\sqrt{3}\,E\cos\varphi}$)

The same symbols with the subscript " 1 " refer to the receiver.

The same symbols with the subscript " 0 " refer to the sending end.

l = distance in miles of this point Q from receiver.

dl = elementary length of line between Q and S.

l_0 = length of line in miles.

r = resistance of wire in ohms per mile.

x = reactance of wire in ohms per mile.

g = leakage conductance, one wire to neutral in mhos per mile.

b = capacity susceptance, one wire to neutral, in mhos per mile.

$z=\sqrt{r^2+x^2}$

$y=\sqrt{g^2+b^2}$

$\epsilon=\tan^{-1}\frac{x}{r}$

$\eta=\tan^{-1}\frac{b}{g}$

For the voltage and current sine functions of the time we may use the symbolic method. Let $\dot{V}$ and $\dot{I}$ be the symbolic expressions for the voltage and current respectively. The symbolic expression for the impedance per unit length of line is

$$\dot{z}=z\,(\cos\epsilon+j\sin\epsilon)=z\,e^{j\epsilon} \qquad (1)$$

and the symbolic expression for the admittance of the leakage circuit per mile of line is

$$\dot{y}=y\,(\cos\eta+j\sin\eta)=y\,e^{j\eta} \qquad (2)$$

Digitized by Google

Applying Kirchoff's laws to the element $d\,l$ of the line, we get

$$\frac{d\,V}{d\,l} = z\,I \tag{3}$$

$$\frac{d\,I}{d\,l} = y\,V \tag{4}$$

Differentiating (3) with respect to l and substituting the value of $\frac{d\,I}{d\,l}$ from (4) gives

$$\frac{d^2\,V}{d\,l^2} = y\,z\,V \tag{5}$$

The integral of this equation is

$$V = A \sinh(\sqrt{y\,z}\,l + \delta) \tag{6}$$

where A and δ are constants of integration.

Substituting (6) in (4), and integrating with respect to l we get

$$I = \sqrt{\frac{y}{z}}\,A \cosh(\sqrt{y\,z}\,l + \delta) \tag{7}$$

Both A and δ may be complex; let their symbolic expressions be

$$A = A\,(\cos\alpha + j\sin\alpha) = A\,e^{j\alpha} \tag{8}$$

$$\delta = \beta + j\,\gamma \tag{9}$$

From (1) and (2)

$$\sqrt{y\,z} = \sqrt{y\,z}\,e^{j\left(\frac{\eta+\epsilon}{2}\right)} = \sqrt{y\,z}\left[\cos\left(\frac{\eta+\epsilon}{2}\right) + j\sin\left(\frac{\eta+\epsilon}{2}\right)\right] \tag{10}$$

$$\sqrt{\frac{y}{z}} = \sqrt{\frac{y}{z}}\,e^{j\left(\frac{\eta-\epsilon}{2}\right)} \tag{11}$$

Digitized by Google

Put

$$\lambda = \frac{\eta - \epsilon}{2} \tag{12}$$

$$m = \sqrt{y z} \cos\left(\frac{\eta + \epsilon}{2}\right) \tag{13}$$

$$n = \sqrt{y z} \sin\left(\frac{\eta + \epsilon}{2}\right) \tag{14}$$

Then (6) and (7) become

$$\gamma = A \sinh\left[(\beta + m\,l) + j\,(\gamma + n\,l)\right] \tag{15}$$

$$I = \sqrt{\frac{y}{z}}\, A \cosh\left[(\beta + m\,l) + i\,(\gamma + n\,l)\right] \tag{16}$$

But

$$\sinh\left[(\beta + m\,l) + j\,(\gamma + n\,l)\right]$$

$$= \sinh(\beta + m\,l)\cos(\gamma + n\,l) + j\cosh(\beta + m\,l)\sin(\gamma + m\,l)$$

$$= M\,e^{j\mu} \tag{17}$$

where

$$M = \sqrt{\sinh^2(\beta + m\,l)\cos^2(\gamma + n\,l) + \cosh^2(\beta + m\,l)\sin^2(\gamma + n\,l)}$$

and

$$\tan\mu = \frac{\tan(\gamma + n\,l)}{\tanh(\beta + m\,l)}$$

Making use of the relations that for any argument u,

$$\sinh^2 u = \frac{\cosh 2u - 1}{2}$$

$$\cosh^2 u = \frac{\cosh 2u + 1}{2}$$

$$\sin^2 u = \frac{1 - \cos 2u}{2}$$

$$\cos^2 u = \frac{1 + \cos 2u}{2}$$

Digitized by Google

the above expression for M may be written

$$M=\frac{1}{\sqrt{2}}\sqrt{\cosh 2(\beta+m l)-\cos 2(\gamma+n l)} \tag{18}$$

Whence, substituting for A its value from (8) and the relation (17), the expression (15) for the voltage at any point along the line becomes

$$V=A\ M\ e^{j(\alpha+\mu)} \tag{19}$$

In an exactly similar manner, we may write

$$\cosh[(\beta+m l)+j(\gamma+n l)]=N\ \epsilon^{j\nu}$$

$$N=\frac{1}{\sqrt{2}}\sqrt{\cosh 2(\beta+m l)+\cos 2(\gamma+n l)} \tag{20}$$

$$\tan\nu=\tan(\gamma+n l)\tanh(\beta+m l) \tag{21}$$

Whence the current at any point along the line is

$$I=\sqrt{\frac{y}{z}}\ A\ N\ e^{j(\alpha+\nu+\lambda)} \tag{22}$$

Hence the effective value of the voltage at any point is $A\ M$ or

$$V=A_0\sqrt{\cosh 2(\beta+m l)-\cos 2(\gamma+n l)} \tag{23}$$

and the effective value of the current at this point is

$$I=\sqrt{\frac{y}{z}}\ A_0\sqrt{\cosh 2(\beta+m l)+\cos 2(\gamma+n l)} \tag{24}$$

where A_0, which is a constant yet to be determined, is put for $\frac{A}{\sqrt{2}}$. The angle by which the current lags behind the voltage, or the power factor angle φ, is

$$\varphi=\alpha+\mu-(\alpha+\nu+\lambda)$$

$$=\mu-\nu-\lambda$$

Digitized by Google

A simple expression for the angle $(\mu-\nu)$ may be derived by making use of the trigonometric relation

$$\tan(\mu-\nu)=\frac{\tan\mu-\tan\nu}{1+\tan\mu\tan\nu}$$

for substituting for $\tan\mu$ and $\tan\nu$ their values from (**17**) and (**21**) we get

$$\tan(\mu-\nu)=\frac{\sin 2(\gamma+n\,l)}{\sinh 2(\beta+m\,l)}$$

Whence the power factor angle at any point along the line is

$$\varphi=\tan^{-1}\left[\frac{\sin 2(\gamma+n\,l)}{\sinh 2(\beta+m\,l)}\right]-\lambda \qquad (\mathbf{25})$$

The power per phase at any point is then

$$P'=V\,I\cos\varphi$$

$$=\sqrt{\frac{y}{z}}\,A_0^2\cos\varphi\,\sqrt{\cosh^2 2(\beta+m\,l)-\cos^2 2(\gamma+nl)}$$

Making use of the relations

$$\cosh^2 u=1+\sinh^2 u$$

$$\cos^2 u=1-\sin^2 u$$

we may write this expression

$$P'=\sqrt{\frac{y}{z}}\,A_0^2\cos\varphi\,\sqrt{\sinh^2 2(\beta+m\,l)+\sin^2 2(\gamma+n\,l)}$$

From (**25**), making use of the trigonometric formula for the cosine of the difference of two angles,

$$\cos\varphi=\frac{\sinh 2(\beta+m\,l)\cos\lambda+\sin 2(\gamma+n\,l)\sin\lambda}{\sqrt{\sinh^2 2(\beta+m\,l)+\sin^2 2(\gamma+n\,l)}}$$

Whence

$$P'=\sqrt{\frac{y}{z}}\,A_0^2\,[\sinh 2(\beta+m\,l)\cos\lambda+\sin 2(\gamma+m\,l)\sin\lambda] \qquad (\mathbf{26})$$

Digitized by Google

At the receiver $l=0$; and at the sending end $l=l_0$. Hence from (**23**), we have that the ratio of the volts E_0 at the sending end to the volts E_1 at the receiver is

$$\frac{E_0}{E_1}=\frac{V_0}{V_1}=\sqrt{\frac{\cosh 2(\beta+m l_0)-\cos 2(\gamma+n l_0)}{\cosh 2\beta-\cos 2\gamma}} \tag{27}$$

From (**24**) the ratio of the current I_0 at the sending end to current I_1 at the receiver is

$$\frac{I_0}{I_1}=\sqrt{\frac{\cosh 2(\beta+m l_0)+\cos 2(\gamma+n l_0)}{\cosh 2\beta+\cos 2\gamma}} \tag{28}$$

From (**26**) the ratio of the power P_0 at the sending end to the power P_1 at the receiver is

$$\frac{P_0}{P_1}=\frac{P_0'}{P_1'}=\frac{\sinh 2(\beta+m l_0)\cos\lambda+\sin 2(\gamma+n l_0)\sin\lambda}{\sinh 2\beta\cos\lambda+\sin 2\gamma\sin\lambda} \tag{29}$$

We have now to determine the two constants β and γ. From (**25**), putting $l=0$, we have

$$\frac{\sin 2\gamma}{\sinh 2\beta}=\tan(\varphi_1+\lambda) \tag{30}$$

and from (**23**) and (**24**) putting $l=0$, and squaring, we have

$$V_1^2=A_0^2(\cosh 2\beta-\cos 2\gamma)$$

$$\frac{z}{y}I_1^2=A_0^2(\cosh 2\beta+\cos 2\gamma)$$

Adding and subtracting these two expressions and taking the ratio of the results gives

$$\frac{\cosh 2\beta}{\cos 2\gamma}=\frac{z I_1^2+y V_1^2}{z I_1^2-y V_1^2}$$

Put

$\rho=\dfrac{z l_0 I_1}{V_1}$ = ratio of total line impedance volts to volts delivered.

Digitized by Google

$\sigma = \frac{y\, l_0\, V_1}{I_1}$ = ratio of total line admittance current to current delivered.

Then

$$\frac{z\, I_1^2 + y\, V_1^2}{z\, I_1^2 - y\, V_1^2} = \frac{\rho + \sigma}{\rho - \sigma}$$

whence

$$\cosh 2\beta = \frac{\rho + \sigma}{\rho - \sigma} \cos 2\gamma \qquad (31)$$

From (**30**)

$$\sinh 2\beta = \frac{\sin 2\gamma}{\tan (\varphi_1 + \lambda)} \qquad (31a)$$

Squaring and subtracting we get

$$1 = \left(\frac{\rho + \sigma}{\rho - \sigma} \right)^2 \cos^2 2\gamma - \frac{\sin^2 2\gamma}{\tan^2 (\varphi_1 + \lambda)}$$

Making use of the trigonometric relations

$$\cos^2 2\gamma = \frac{1}{1 + \tan^2 2\gamma}$$

$$\sin^2 2\gamma = \frac{\tan^2 2\gamma}{1 + \tan^2 2\gamma}$$

and solving for $\tan 2\gamma$, we get

$$\tan 2\gamma = \frac{2 \sqrt{\rho\, \sigma} \sin (\varphi_1 + \lambda)}{\rho - \sigma} \qquad (32)$$

Note that from (**31**) and (**31***a*) that $\sin 2\gamma$ and $\cos 2\gamma$ have respectively the same algebraic signs as the numerator and denominator of this fraction. This is important since the algebraic sign of the tangent alone does not fix the quadrant in which an angle lies. The value of 2γ may be taken directly from the trigonometric scale on Chart No. 3. (If the second

Digitized by Google

Directions for Calculating Regulation, Power Loss, and Power Factor

Let l = length of each wire in miles.
E = volts between wires at receiving end.
I = amperes per wire delivered to receiver.
k = power-factor of receiver as a decimal fraction.
ϕ = cos-^{1} k = power-factor of receiver (positive for lagging current).
Z = equivalent impedance of receiver per mile of line

$$= \frac{E}{\sqrt{3}\, l\, I} \text{ for three-phase line} = \frac{E}{2\, l\, I} \text{ for single-phase line.}$$

r = resistance per mile of each wire in ohms (see Line Constant Chart).
x = reactance per mile of each wire in ohms (see Line Constant Chart).

$$\epsilon = \tan^{-1}\frac{x}{r} = \cot^{-1}\frac{r}{x} \text{ (see scale for Trigonometric Functions).}$$

b = capacity susceptance per mile of each wire in mhos (see Line Constant Chart).

To find q = power loss as a percentage of power delivered.
p = volts lost in line as a percentage of volts delivered.
k_0 = power-factor of sending end of line

Procedure:

1. *Line Capacity Neglected*

$$q = \frac{100\, r}{Z\, k}$$

Calculate the percentage impedance drop d, where

$$d = \frac{100\, r}{Z \cos \epsilon}$$

Find the difference between the line power-factor angle ϵ and the load power-factor angle ϕ, that is, the angle

$$\epsilon - \phi$$

Then p is the ordinate of the point which is on the curve marked with the number equal to the numerical value of $\epsilon - \phi$ and which has the abscissa d.

$$k_0 = \left(\frac{100+q}{100+p}\right) k$$

2. *Line Capacity Taken into Account.*

Calculate q and p as above, neglecting capacity. Then true per cent power loss is

$$q' = q - 100\, b\, r\, l^2 \tan \phi$$

To find the true per cent drop p' measure down from the point corresponding to p on the ordinate scale a distance equal to $b \times l^2$ measured on the "capacity correction scale." The resultant ordinate is then the true per cent voltage drop.

To find the current at sending end of line calculate the quantity

$$d' = 100\, b\, Z\, l^2$$

Then find on the curve marked with the number equal to $90° + \phi$ the point which has the abscissa d', and measure vertically downward from this point a distance equal to $b \times l^2$ on the "Capacity correction Scale." The resultant ordinate p_1 is the per cent excess of the current of the sending end I_0 over the receiver current, I, that is

$$I_0 = \left(\frac{100+p_1}{100}\right) I$$

The power-factor at the sending end is

$$k_0' = \frac{(100+q')\, k}{(100+p_1)\,(100+p')}$$

Example: Three-phase line, 60 cycles, No. 0000 B. & S. wire, 6 ft. apart, 100 miles long.

	Capacity neglected	Capacity taken into account
$E = 66{,}000$		
$I = 100$		
$k = 0.95$ lagging		
$\phi = 18.2$		
$\tan \phi = 0.328$		
$Z = 346$		
$r = 0.267$		
$x = 0.727$		
$\epsilon = 69.8°$		
$\cos \epsilon = 0.344$		
$b = 6.03 \times 10^{-6}$		
	$q = 8.13\%$	$q' = 7.60\%$
	$d = 22.4\%$	$b \times l^2 = 0.0438$
	$\epsilon - \phi = 51.6°$	$p' = 13.6\%$
	$p = 15.4\%$	$d' = 20.9\%$
	$k_0 = 89.0\%$	$90 + \phi = 108.2°$
		$p_1 = -6.7\%$
		$I_0' = 93.3$ amp.
		$k_0' = 96.5\%$

[Pender and Thomson

p = Percent Voltage Drop

p = Percent Voltage Rise

Digitized by Google

Digitized by Google

member of (**32**) is greater than unity use the reciprocal which is equal to the cot 2γ). From (**30**) we then have

$$\sinh 2\beta = \frac{\sin 2\gamma}{\tan(\varphi_1+\lambda)} \tag{33}$$

from which 2β may be obtained from Chart No. 5.

Approximate Equations for Ordinary Lines.

In case the length of the line does not exceed 100 miles when the frequency is 60 cycles or 200 miles when the frequency is 25 cycles the above equations may be greatly simplified by making use of an approximation which will not introduce an appreciable error in any case likely to arise in practice.

The simplification results from the following substitutions in equations (**27**) to (**29**)

$$\begin{gathered}\cosh 2ml = 1+2m^2l^2 \\ \sinh 2ml = 2ml \\ \cos 2nl = 1-2n^2l^2 \\ \sin 2nl = 2nl\end{gathered} \tag{34}$$

where nl is expressed in radians. These approximations are accurate to within 2 per cent for $2ml$ less than 0.35 and for $2nl$ less than 0.35 radians or 20 deg.

From equations (**31**), (**31***a*) and (**32**) we have

$$\sinh 2\beta = \frac{2\sqrt{\rho\sigma}\cos(\varphi_1+\lambda)\cos 2\gamma}{\rho-\sigma} \tag{35}$$

$$\cosh 2\beta = \frac{\rho+\sigma}{\rho-\sigma}\cos 2\gamma \tag{36}$$

$$\sin 2\gamma = \frac{2\sqrt{\rho\sigma}\sin(\varphi_1+\lambda)\cos 2\gamma}{\rho-\sigma} \tag{37}$$

Substituting equations (**34**) to (**37**) in (**27**) to (**29**) we get, for no leakage

$$\frac{E_0}{E} = \sqrt{1+2\rho\cos(\epsilon-\varphi_1)+\rho^2-b\,x\,l_0^2} \tag{38}$$

Digitized by Google

$$\frac{I_0}{I} = \sqrt{1+2\,\sigma\cos(90-\varphi_1)+\sigma^2-b\,x\,l_0^2} \qquad (39)$$

$$\frac{P_0}{P} = 1+\frac{\rho\cos\epsilon}{\cos\varphi}-b\,r\,l_0^2\tan\varphi_1 \qquad (40)$$

It is interesting to note that these last three equations, when b is put equal to zero, are identical with the relations which follow immediately from the vector diagram, Fig. 5, of the line and load when the capacity of the line is neglected.

Summary

In the working formulas given below, the symbols for voltage, current, etc., at the receiver will be written without the sub-

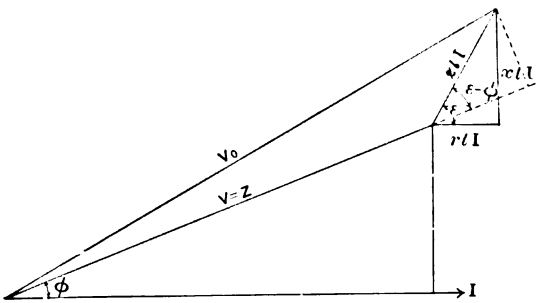


Fig. 5

scripts, and l will be used to designate the length of the line from receiver to sending end. The power will also be expressed in kilowatts. The leakage will be assumed zero.

P = kilowatts delivered to receiver.
E = volts between wires at receiver.
K = power factor of receiver.
$\varphi = \cos^{-1} K$ = power factor angle of receiver (see Chart No. 3.)
I = amperes taken by receiver. (For a three phase line $I = \frac{P\times 1000}{\sqrt{3}\,E\,K}$; for a single phase line $I = \frac{P\times 1000}{E\,K}$).

The same symbols with the subscript zero refer to the sending end.

l = distance of transmission in miles.
r = resistance of wire in ohms per mile (see Chart No. 3).

Digitized by Google

x = reactance of wire in ohms per mile (see Chart No. 3).

b = capacity susceptance, one wire to neutral, in mhos per mile. (See Chart No. 3).

$\epsilon = \tan^{-1}\frac{x}{r}$ = power factor angle of the line (see Chart No. 3).

Z = equivalent impedance of receiver terminal to neutral, per mile of line.

$= \frac{E}{\sqrt{3}\, l\, I}$ for a three phase line;

$= \frac{E}{2\, l\, I}$ for a single phase line.

Exact Method. Since the leakage is assumed zero, the admittance y is equal to b and the power factor angle of the leakage circuit is 90 deg. Hence to determine the voltage, current, etc., at the sending end proceed as follows:

First calculate the constants

$$\lambda = \frac{90 - \epsilon}{2} \tag{41}$$

$$u = 2\, l \sqrt{\frac{b\, x}{\sin \epsilon}} \sin \lambda \tag{42}$$

$$\theta = 114.6\, l \sqrt{\frac{b\, x}{\sin \epsilon}} \cos \lambda \tag{43}$$

$d = \frac{100\, r}{Z \cos \epsilon}$ = per cent ratio of impedance volts to volts delivered (44)

$d' = 100\, b\, Z\, l^2$ = per cent ratio of charging current to current delivered. (45)

$$\theta_0 = \tan^{-1}\left[\frac{2\sqrt{d\, d'}\sin(\varphi + \lambda)}{d - d'}\right] \tag{46}$$

The algebraic signs of $\sin \theta_0$ and $\cos \theta_0$ are respectively the same as the numerator and denominator of this fraction; this fixes the quadrant in which θ_0 lies.

$$u_0 = \sinh^{-1}\left[\frac{\sin \theta_0}{\tan(\varphi + \lambda)}\right] \tag{47}$$

Digitized by Google

Then

$$\frac{E_0}{E} = \sqrt{\frac{\cosh(u_0+u)-\cos(\theta_0+\theta)}{\cosh u_0-\cos\theta_0}} \tag{48}$$

$$\frac{I_0}{I} = \sqrt{\frac{\cosh(u_0+u)+\cos(\theta_0+\theta)}{\cosh u_0+\cos\theta_0}} \tag{49}$$

$$\frac{P_0}{P} = \frac{\sinh(u_0+u)\cos\lambda+\sin(\theta_0+\theta)\sin\lambda}{\sinh u_0\cos\lambda+\sin\theta_0\sin\lambda} \tag{50}$$

The power factor angle φ at the sending end may also be determined directly from the formula

$$\varphi_0 = \tan^{-1}\left[\frac{\sin(\theta_0+\theta)}{\sinh(u_0+u)}\right]-\lambda \tag{51}$$

An excellent check on the results obtained is to compare the value of $\cos\varphi_0$ determined from this formula with the value of the power factor calculated from the voltage E_0 current I_0, and power P_0 determined from the three preceding formulas. (For a three phase line $\cos\varphi_0 = \frac{1000\,P_0}{\sqrt{3}\,E_0\,I_0}$; for a single phase line $\cos\varphi_0 = \frac{1000\,P_0}{E_0\,I_0}$).

Approximate Method, Neglecting Line Capacity. In the case of a short line (*i.e.*, $10^4\,b\,x\,l^2$ negligible compared with d) the relations between the voltage, current and power at the two ends of the line are as follows. Let

$p = 100\,\frac{E_0-E}{E}$ = the per cent ratio of the difference in volts at the two ends to the volts delivered, *i.e.*, the per cent " volts drop ".

$q = 100\,\frac{P_0-P}{P}$ = the per cent ratio of power lost in line to power delivered, *i.e.*, the per cent " power loss ".

Then

$$p = \sqrt{10^4+200\,d\cos(\epsilon-\varphi)+d^2}-100 \tag{52}$$

Digitized by Google

$$q = \frac{d \cos \epsilon}{K} = \frac{100\, r}{K\, Z} \qquad (53)$$

$$K_0 = \frac{100+q}{100+p} \cdot K \qquad (54)$$

Chart No. 5 gives a graphical solution of equation (**52**). The ordinate scale of this chart gives directly the value of the per cent volts drop when the per cent impedance drop d and the difference in the power factor angles of the line and load are known. The method of using the chart is described in detail on the chart itself. Each of the curves on the chart was drawn by plotting the values of

$$200\, d \cos (\epsilon - \varphi) + d^2$$

as actual vertical distance against d as abscissas; the numbers on the curves give the corresponding values of $(\epsilon - \varphi)$. The scale of ordinates marked on the left is a square root scale, the numbers giving the value of

$$\sqrt{10^4 + 200\, d \cos (\epsilon - \varphi) + d^2} - 100$$

Note that since $\cos (\epsilon - \varphi) = \cos (\varphi - \epsilon)$, the algebraic sign of the resultant angle $(\epsilon - \varphi)$ is immaterial. The curve marked with a given number, say 50, is to be used whether $\epsilon - \varphi = +50$ or $\epsilon - \varphi = -50$.

Approximate Method when Line Capacity is Taken into Account. For longer lines (*i.e.*, when $10^4\, b\, x\, l^2$ is not negligible in comparison with d), the following close approximations hold, provided the length of the line is not over 100 miles for 60 cycles or over 200 miles for 25 cycles. Let

p' = true value of the per cent volts drop when corrected for capacity effect.

q' = true value of the per cent power loss when corrected for capacity effect.

$p'_i = 100\, \frac{I_0 - I}{I}$ = the per cent ratio of the difference in the current at the two ends of the line to the current delivered; *i.e.*, the per cent "current loss" (p_i will in general be negative for a lagging current at the receiver).

Digitized by Google

Then

$$p' = \sqrt{10^4 + 200\, d \cos(\epsilon - \varphi) + d^2} - 10^4\, b\, x\, l^2 - 100 \qquad (55)$$

$$p_i' = \sqrt{10^4 + 200\, d' \cos(90 + \varphi) + (d')^2} - 10^4\, b\, x\, l^2 - 100 \qquad (56)$$

$$q' = q - 100\, b\, r\, l^2 \tan \varphi \qquad (57)$$

$$K_0' = \frac{(100 + q')\, K}{(100 + p')\,(100 + p_i')} \qquad (58)$$

Equations (**55**) and (**56**) may be solved graphically by the use of Chart No. 5. Distances on the " capacity correction scale " in the upper left hand corner of this chart are laid off equal to $10^4\, b\, x\, l^2$, the number on this scale giving the corresponding value of $b\, x\, l^2$. The method of making this correction is described on the chart itself.

Chart No. 5 may also be used to calculate the regulation in any case where the voltage drop is due to the impedance of the apparatus. For example, it may be used to calculate the regulation of a transformer when ϵ is taken equal to the power factor angle of the equivalent impedance of the transformer and d is taken equal to the per cent ratio of the equivalent impedance of the transformer to the equivalent impedance (V/I) of the load, or to calculate the regulation of a generator when ϵ is taken equal to the power factor angle of the equivalent impedance of the generator and d is taken equal to the per cent ratio of the synchronous impedance of the generator to the impedance of the load (V/I).

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

TRANSMISSION SYSTEM OF THE GREAT WESTERN POWER COMPANY

BY J. P. JOLLYMAN

The Great Western Power Company operates a long-distance, extra high-tension transmission system which extends from its hydroelectric plant at Big Bend, 16 miles north of Oroville, Cal., to Oakland, Cal. The nominal line voltage is 100,000, at 60 cycles. The length of the main line is 153.6 miles. A branch line 1.1 miles long taps the main line 136.5 miles from Big Bend. Both the main and branch lines are double circuit. Both are supported on steel towers.

1. The high tension sides of all the transformers are delta connected. There is no connection to ground, except through the electrolytic lightning arresters.

2. One ground wire, supported on the apex of the towers, is used. This is grounded at every tower.

3. The standard span is 750 feet. 3/0, seven-strand copper cable is used on the main line, No. 6 copper on the branch. Each circuit is completely transposed about every 10 miles. The arrangement of the conductors is shown in Fig. 1.

The longest span with regular towers and cable is 1,998 feet. The longest span is 2740 feet. This is across the San Joaquin River near Antioch. Special towers are used. The conductors clear high water 125 feet. The six conductors are in a horizontal plane, 15 feet apart.

4. We have never yet had any lightning whatever.

5. The measured value of the charging current is very nearly the same as the value determined by using the ordinary formula for charging current based on the capacity of two parallel con-

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting

Digitized by Google

ductors. The distance between the conductors is taken as the average distance of 13.33 feet.

VALUES OF CHARGING CURRENT

Volts at Big Bend	Computed current	Observed Current	Observed Kv-a.
70,000	35.7	36.0	4360
80,000	40.8	41.5	5750
90,000	46	47	7330

6. Line insulators used. G. E. strain type, Locke strain type, Thomas strain and suspension types. Only three or four insulators have broken down during the past year. In no case have we any reason to believe that the insulators may not have been damaged mechanically before it failed electrically. We consider that the suspension insulator is a success.

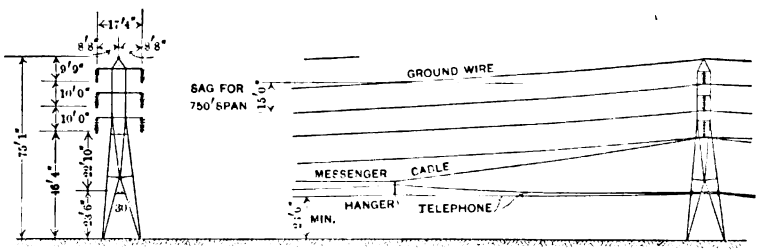


FIG. 1

We have had no trouble with swinging of conductors with suspension insulators.

7. G. E. type T and type K-10 oil switches are both used. We have had no difficulty in opening load, short circuit or charging current. The indications are that these switches could be safely used on a considerably larger system than we now operate.

8. We have all kinds of load connected to our system, including synchronous motors. No attempt is made to neutralize the charging current by reducing the field on any synchronous load. Under ordinary conditions the power factor at the generating station is nearly unity.

For the convenience, speed and safety of operation, each generating unit should have a capacity of at least equal to the charging current of one line. In our case this means units of about 10,000 kw. We have at present four 10,000 kw. generators

Digitized by Google

at Big Bend, each with a 10,000 kw., three-phase transformer. The station is planned to ultimately contain eight 10,000-kw. units.

9. *Transformer Terminals.* Oil-filled terminals were supplied. It has been found difficult to maintain them free from the possibility of leakage. They have been refilled with compounds designed to reduce the chance of leakage.

Oil Switch Terminals. We have used compound-filled terminals. Experience has shown that compounds for use in high-tension terminals must be very carefully tested in practical operation before their suitability can be definitely decided upon.

Outlets. The outlets from our buildings are primarily composed of plate glass windows five feet square, through the center of which the conductor passes. Various arrangements of extra insulation around the conductor have been tried. Our experience seems to show that the best arrangements of plate glass windows is to use a bare conductor of large diameter and leave as large an opening around the conductor as climatic conditions permit. The window should be so protected that rain may not run over the surface of the glass.

10. We are using electrolytic lightning arresters at each end of the main line. Having had no lightning, we have had no experience with them as lightning arresters. We have operated one circuit without lightning arresters at either end for some time. Our experience has shown that they can not absorb much energy without being damaged and therefore their critical voltage must be higher than any dynamic voltage that may ever occur upon the system.

11. We have had no sleet, nor any trouble from wind since the line was finished.

12. There is no appreciable corona effect on the main line. Probably no very great increase in voltage would produce corona on the branch line of No. 6 copper wire. No part of the line is over 2,000 feet elevation above sea level.

13. The telephone line is strung on the towers. In regular spans it is supported by three hangers which are carried by a grounded messenger cable. Drainage coils consisting of the 2200-volt winding of a two-kw. transformer with the center point grounded are used at both ends and in the center of the line. These reduce the voltage to ground of the telephone line to a very low value, probably less than 100 volts. This obviates the necessity for especially high insulation and reduces the noise due

Digitized by Google

to unequal leakage. Highly insulated repeating coils are used where connections are made to telephones at which it is impossible to insure adequate insulation to ground of the person using the instrument. The telephone line is transposed at every tower where the towers are evenly spaced. Where the tower spacing is uneven the distance between transpositions is made as even as possible. The service obtained from this line is very satisfactory and is not more than momentarily interrupted by disturbances on the power line.

14. The only difficulty in maintaining satisfactory voltage regulation is at times when changes in load amounting to a large percentage of the total occur suddenly.

15. Steel towers whose general dimensions are given in Fig. 1 are used. Foundations suitable to the character of the ground must be used. Piles are used in very soft ground, cut off below the ground water level. The tower footing is attached to the top of the pile. All the tower footings are set in concrete. There have been no signs of corrosion in two years.

16. The system has been operated at 100,000 volts since November 1, 1909.

General Comments

Our experience indicates that the following points should receive special attention when planning an extra high tension, long distance transmission system:

Generator capacity to handle the charging current.

Provision for the proper control of the system under all possible emergency conditions.

If delta operation is contemplated, insulation should be provided that will safely withstand the full delta voltage. The insulation should be of a character especially adapted to withstand transient voltage strains considerably in excess of the delta voltage.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

TRANSMISSION SYSTEM OF THE SOUTHERN POWER COMPANY

BY W. S. LEE

The following data is submitted in regard to the operation of the high-tension transmission lines of the Southern Power Company, of Charlotte, N. C.

1. 100,000 volt system. Transformers for stepping up delta connected on 44,000-volt side and star-connected on 100,000-volt side, with neutral grounded. No resistance. 44,000-volt system is delta-delta non-grounded.

2. Overhead ground wires are used. One from peak to peak of the twin circuit steel towers upon which the two three-phase circuits are arranged in vertical planes, one on each side of each tower. Towers are not set in concrete, thus the ground wire is grounded at each tower, as each of the four legs is set about eight feet in the earth. Ground wire is $\frac{3}{8}$-in. S. M. strand.

3. Conductors are 2/0 seven-strand copper and 2/0 seven-strand aluminum. Our standard span on 100,000-volt circuit is 600 ft., and we always have 20 ft. clearance at the middle point of sag. We use both copper and aluminum and make very little difference in sag. On 100,000-volt towers there are two circuits; three wires held vertically on each side of towers. Length of cross-arm 15 ft. 10 in. on old towers, 18 ft. 4 in. on new towers. Vertical distance between cross-arms 8 ft. 4 in. on old towers, 10 ft. 6 in. on new towers. We have many spans over 1000 ft. long and several 1500-ft. and 1600-ft. spans in both the copper and aluminum. We use strain towers at each end of these spans and keep the strain on the conductor the same as on the short spans.

4. Frequent lightning storms. The 100,000-volt lines stood

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

the lightning better the one season since they have been in service than the lower voltage lines.

From January 1, 1910 to date the Great Falls-Greenville, line, 96½ miles long, 858 towers, had eight shut-downs due to lightning damaging either the 100,000-volt apparatus or lines. Time lost, 39 minutes.

From January 1, 1910 to date the Great Falls-Greensboro line, 161 miles long, of which 18 miles is a branch 100,000-volt pole line with 338 poles—main line with 1300 towers—had 14 shut-downs due to lightning damaging 100,000-volt apparatus or lines. Time lost, 59 minutes.

5. The only time the charging current was measured was when we started up the first 143 miles. We had 88,000 volts at the step-up transformers and we measured on the 2440-volt side of the transformers 1436 amperes, which is 6185 kv-a. The calculated current is 1450. This was on 2/0 copper at 60 cycles.

6. Some hooks have pulled out of insulators; these were the only defects we have found. We have never had a line put out of service due to failure of insulators, except during a sleet storm when three hooks pulled out. Insulators swing with the line in the wind. We have had no trouble from circuits on opposite sides of the tower swinging together and have never observed any dangerous or noticeable tendency to do so.

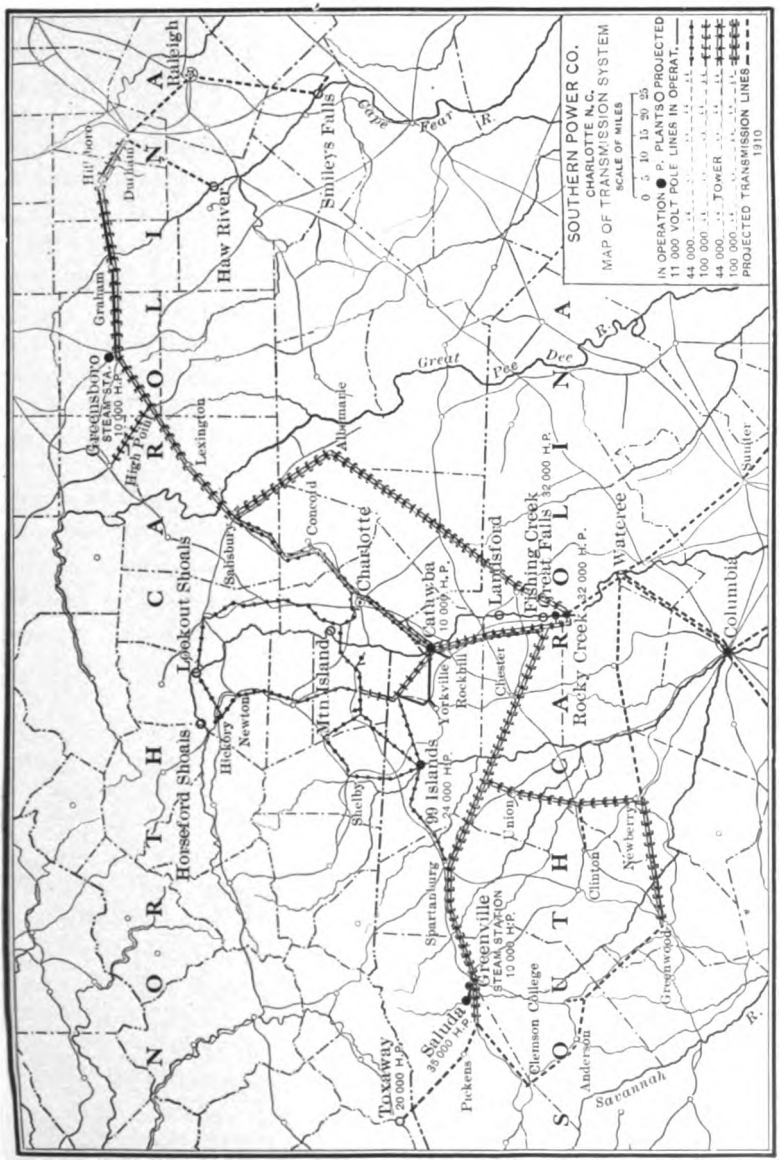
7. G. A. type switch with condenser terminals are used. There has been no more trouble switching and handling the 100,000-volt line than we had with our 44,000-volt and 10,000-volt lines. The same methods of operation, repair, control and distribution used on the 100,000 volt line as on other lines. There are 13 100,000-volt substations, in most of which transformation is made direct from 100,000-volts to 2300-volts by a bank of three 1000 kw. transformers, connected delta-delta.

8. There is practically no synchronous receiving apparatus on the lines. The minimum size of transformers is 1,000 kv-a. The minimum size of generators is 750 kw. in the Catawba plant, which is often in parallel with other stations, all of which supply the 100,000-volt transformers from the 44,000-volt system. The smallest generators ever used exclusively on 100,000-volt lines are 3,000 kw. and never less than three for the two lines.

22.....3,000 kw. generators
4..... 900 " "
4..... 750 " "

are connected to the 44,000-volt system from which the 100,000-volt system is derived through six 4,000-kv-a. transformers.

Digitized by Google



Digitized by Google

9. Porcelain bushings set into 5-ft. square slate slabs are used as outlets. Only one has broken down, and this was caused by bushing being cracked. There has been very little trouble with terminals except in a few damp places.

10. Two sets of 100,000-volt electrolytic arresters, each consisting of four units, are in successful and satisfactory operation.

11. Wind has caused no trouble whatever, and outside of three hooks pulling out soon after the line was put up, sleet has caused no trouble.

12. Have no corona effects except that in one case a very high resistance ground through a line entrance bushing caused the small No. 2 copper equivalent aluminum to glow.

13. We have had more telephone disturbance than with any other line.

14. In regard to the matter of voltage regulation, there is no distinction between the 100,000-volt lines and the 44,000-volt lines.

15. The towers which are set in earth, have been erected about 18 months and have given no trouble because of corrosion or through unstable anchorages.

16. We have been operating at 100,000 volts since October 24, 1909.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

TRANSMISSION SYSTEM OF THE GREAT FALLS POWER COMPANY

BY M. HIBGEN

The Great Falls Power Company is at present operating a total of 282 miles of transmission line at 100,000 volts. The principal transmission is from Great Falls to Butte, Montana, a distance of 130 miles. Over this distance two separate, single-circuit, tower lines are used, a single line being extended from Butte to Anaconda, a distance of 22 miles.

1. All transformers connected to the system are delta connected, this form of connection being very satisfactory in every way.

2. Above the transmission wires are located two ground wires consisting of $\frac{3}{8}$-in. seven-wire, Siemens Martin steel strand, galvanized. These ground wires are clamped to the steel towers and are thus grounded at every tower through the tower legs. The tower legs extend six feet into the earth, and terminate in flat steel feet, which act as ground plates. No additional ground is provided.

3. The standard span for level country is 600 ft. In hilly country, however, there is no regularity in the length of the spans, and spans of from 1000 to 2000 ft. are common, no special construction being employed except to side guy the towers. The conductors are spaced 10 ft. 4 in., and all three conductors lie in a horizontal plane with no transpositions whatever. The conductor is No. 0 B. & S. gauge, six-wire, hard drawn copper strand with hemp center. The normal clearance of wires from the earth is 29 feet.

The longest span in the line is 3034 ft., and occurs at the crossing of the Missouri River. In this span $\frac{3}{8}$-in., Siemens Martin

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

steel strand is substituted for the copper conductors, and a spacing of 20 ft. between wires is employed, two conductors only being supported by each tower. Standard towers and insulators were used, the insulators being doubled.

4. During the summer severe lightning storms are frequent in the vicinity of the line, and several of these have occurred since the line was put in commission at 100,000 volts but as yet no shut-downs have been occasioned by lightning and only mild discharges have taken place over the lightning arresters. It is believed that the overhead ground wires are largely responsible for this immunity from lightning.

5. The charging current of 130 miles of single line at 60 cycles and 100,000 volts at the generating end is 39 amperes per wire or 0.3 ampere per mile. This current was measured directly with a high voltage ammeter, and checks closely with the calculated charging current.

6. The insulators used are of the suspension type and consist of six units, 10 in. in diameter, with the under side of each unit corrugated. The caps and pins are cemented to the porcelain with Portland cement. The insulators have an ultimate strength of approximately 10,000 lb. and will flash over wet at somewhat over 300,000 volts. Up to the present time there has not been a single insulator failure, either mechanical or electrical.

It is true that shortly after the line was erected an insulator was shot in two by a high powered rifle, the bullet cutting a deep groove in the forged steel pin, cutting in two the clevis ears and destroying the porcelain of one unit. This, however, could hardly be classed as a failure.

No difficulty has been experienced with the insulators swinging in the wind. With a 60-mile wind blowing at right angles to the line it is believed that the insulators will swing side-ways and stand at an angle of approximately 40 deg. with the vertical. The maximum deflection observed so far, however, has not been over 30 deg. A considerable deflection has been noticed in insulators which are located between a long span and a short span due to changes in temperature. The tension in a short span varies more with changes in temperature than does the tension in a long span, consequently during cold weather the insulators deflect along the line toward the short span while in hot weather the deflection is in the opposite direction. This action deserves considerable attention, and to accommodate the different positions of the insulator at different times of the year

Digitized by Google

a wire clamp should be employed with a long bearing surface on the wire and a relatively short distance between the wire and the hinged point which supports the clamp. This form of clamp is desirable to prevent a sharp bend in the wire when the insulator stands at either extreme of its swing.

7. The line is controlled at each end by 100,000-volt oil switches, solenoid operated, having a double vertical break. The switches are top connected through oil filled bushings. These switches have been entirely satisfactory and have readily broken the short circuit current supplied by the 21,000 kilowatt plant feeding the lines. To sectionalize the line out-door, double air break switches are used of the three-pole, revolving arm type. The switch blades and jaws are mounted upon pedestal insulators made up of six insulator units in series very similar to the regular suspension insulators except that the cap of one unit is extended upward to form the pin of the next, thus making the insulators as a whole rigid. These switches have not as yet been used to break any charging current but from the standpoint of good insulation and mechanical strength and ease of operation, they have been very satisfactory.

8. The charging current of the line is at present entirely supplied by the main generating plant, which has a total capacity of 21,000 kw., divided into six generating units of 3,500 kw. each.

The output of two generating units is utilized near the generating plant consequently there are at present installed only four banks of 100,000-volt step-up transformers, each bank having a capacity of 3,600 kw. The charging current of one line is well above the normal rated capacity of one generating unit. It has been found, however, that one generating unit and bank of transformers can readily supply the charging current of one line for a short time.

The plant is now fully loaded with an induction motor load and the lagging current taken by the induction motors so nearly balances the charging current of the line that the power factor at the generating plant averages 99 per cent.

There are installed in Butte three 1200-h.p. synchronous motors direct connected to air compressors. These are not yet connected to the line but will be in a short time, and it is expected that they will aid slightly in regulating the voltage at Butte.

9. The 100,000-volt outlets at the Rainbow Plant and at the

Digitized by Google

Butte substation, as well as the switching station at the middle of the line, are through the roofs of the buildings. Oil filled porcelain bushings are used, and these have proved entirely satisfactory. All transformer bushings and switch bushings are oil filled and as yet have caused no trouble.

10. Electrolytic lightning arresters are used at both ends of the line and in the middle, the latter being installed in the switching station. These arresters have discharged during lightning storms, and usually discharge when any high tension switching is done.

The original pedestal insulators upon which the horn gaps for these arresters were mounted proved weak mechanically. Two insulators broke off at the bottom connection without apparent cause. These have since been replaced with the type of insulator used on the line-sectionalizing switches and no further trouble has been experienced.

11. The line has successfully withstood winds estimated at 60 miles per hour, and has been through one sleet storm where sleet formed on the wires "to a diameter of six inches", as reported by one patrolman. This, however, was doubtless an exaggeration.

12. When the line was first put in commission corona was plainly visible on every live part of the system. The corona gradually became less until after about three weeks no corona at all was visible except in a few places in the stations, such as the points of switch blades and other sharp projections. It is believed that this corona formed on small points or other roughnesses caused by the rough handling of the wire and that these have gradually worn off or burned off.

13. A private telephone line parallels the transmission line from Great Falls to Butte. This line is erected on wooden poles and runs midway between the two tower lines at a distance of 30 ft. from each. There was considerable static and much noise on this line when first put into operation. Reactance coils bridged across the line with their middle points grounded were installed at each end of the line and in the middle, and these reduced the induced voltage to about 50 volts between wires and ground, and did away almost altogether with the noise. The line now gives excellent service, and is easier to talk over than the lines of the Bell Company.

14. At no load there is a rise in voltage on the line of 3.5 per cent. With a load of 15,000 kw. at 85 per cent power factor on

Digitized by Google

the two lines the drop in voltage is 7 per cent. With all this load on one line the drop in voltage is 17.5 per cent. Taps are provided on the high-tension winding of the step-up and step-down transformers, and the step-down transformers are connected on a 10 per cent lower tap than are the step-up transformers thus compensating for a drop of 10 per cent. When it is necessary to carry the full load on one line the generating plant raises its voltage 10.5 per cent to take care of the additional drop.

The switching station, which has been referred to, will provide a cross-over in the middle of the line so that it will be necessary to cut out only half of one line in case of accident. This will considerably improve the regulation of the line as a whole.

15. The towers have four legs and a single horizontal cross arm. The wires are supported at the two ends and in the middle of the cross arm and hang 40 ft. from the ground at the tower. The cross arm is supported at two points, each midway between the middle wire and the outside wire. The two ground wires are supported above the cross arm near its points of support.

The tower is composed entirely of angles and flats, all connections being by means of bolts. The cross arm is made of two 4-in. channels placed back to back and separated in the middle. The tower is erected on four angle iron stubs set six feet in the ground, the bottoms of these stubs terminating in flat feet made of short pieces of channel section having an area of 144 sq. in. each. All parts of the tower are galvanized.

16. The system has been operating at 100,000 volts for six months and nothing has developed as yet to indicate that the operation of a 100,000-volt system is any more difficult than the operation of a 50,000-volt system. On the other hand, it is believed that the extra high insulation provided for this voltage prevents many break downs, due to lightning and surges, which would occur on a system operating at 50,000 or 60,000 volts with insulators designed for a factor of safety of two or three, as is common with such systems.

After all, the normal voltage of a long transmission system has little to do with the voltage which must be insulated against. It is the abnormal voltages, caused by lightning, switching and accidental grounds, which really test the insulation of a system such as this.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26–30, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

SOME RECENT TESTS OF OIL CIRCUIT BREAKERS

BY E. B. MERRIAM

INTRODUCTION

Whenever an electrical circuit carrying considerable energy is opened in oil, gases are generated. These expand and rise, and tend to force the oil out of the containing vessel. They also form with air explosive mixtures, and either explode, or burn for a considerable length of time when ignited. It is important, therefore, that oil circuit breakers be provided with strong oil containing vessels in order that they may withstand the high initial stresses which are often present under certain conditions and also that suitable provision be made for retaining the oil.

In order to check tests made on moderate capacity circuits and to study the operation of oil circuit breakers and current limiting reactances on circuits of large capacity, under various conditions, arrangements were made through the courtesy of the management of the Commonwealth Edison Company of Chicago, Ill., to use one of its generating units as a source of power for tests.

APPARATUS

These tests were made at the Fisk Street Station (Fig. 1) during the early part of the year, using a three phase, 12,000-kw., 9000-volt, 25-cycle, turbo-alternator.

The following apparatus was made up at the factory and shipped for test:

3 current-limiting reactances, Fig. 2 (no iron core).

1 standard triple-pole type F form H-3 oil circuit breaker (8 in. diameter oil vessel).

2 special triple-pole type F form H-3 oil circuit breakers.

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

1 standard triple-pole type F form H-6 oil circuit breaker (10 in. diameter oil vessel).
3 standard single-pole type F form K-2 oil circuit breakers.

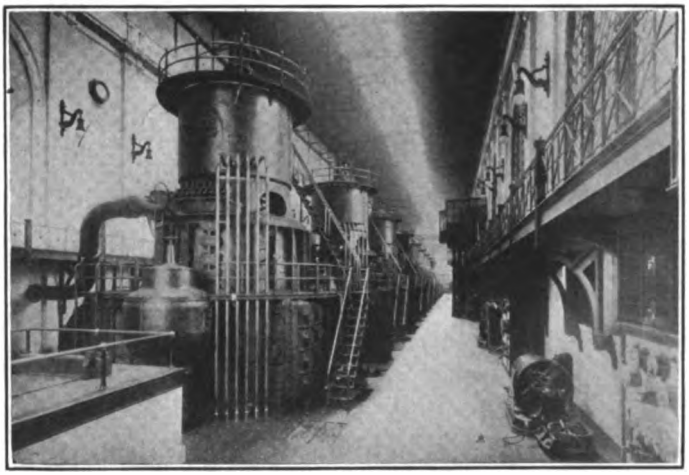


FIG. 1.—Interior of Fisk street station, Commonwealth Edison Company

1 special triple-pole type F form K-12 oil circuit breaker.
3 special single-pole type F form K-12 oil circuit breakers.

The connections are given in Fig. 3.

For the purposes of observation and measurement, use was made of two three-element electromagnetic oscillographs, one three-element arc length recorder, a special gas engine indicator, special spark gaps, movement recording devices, etc.

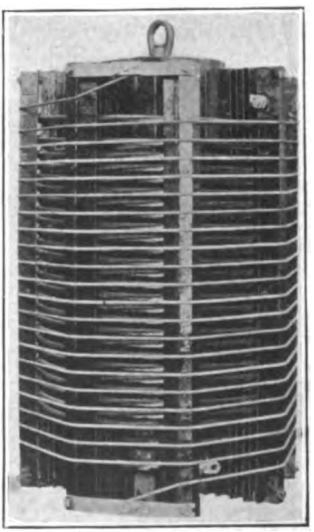


FIG. 2.—One unit of generator current-limiting reactances

METHOD OF TESTS

Practically all of the tests were either three phase or single phase short circuits, some to ground and some between phases. The short circuits were made by closing the triple pole type F form K-12 oil circuit breaker shown in Fig. 4.

Digitized by Google

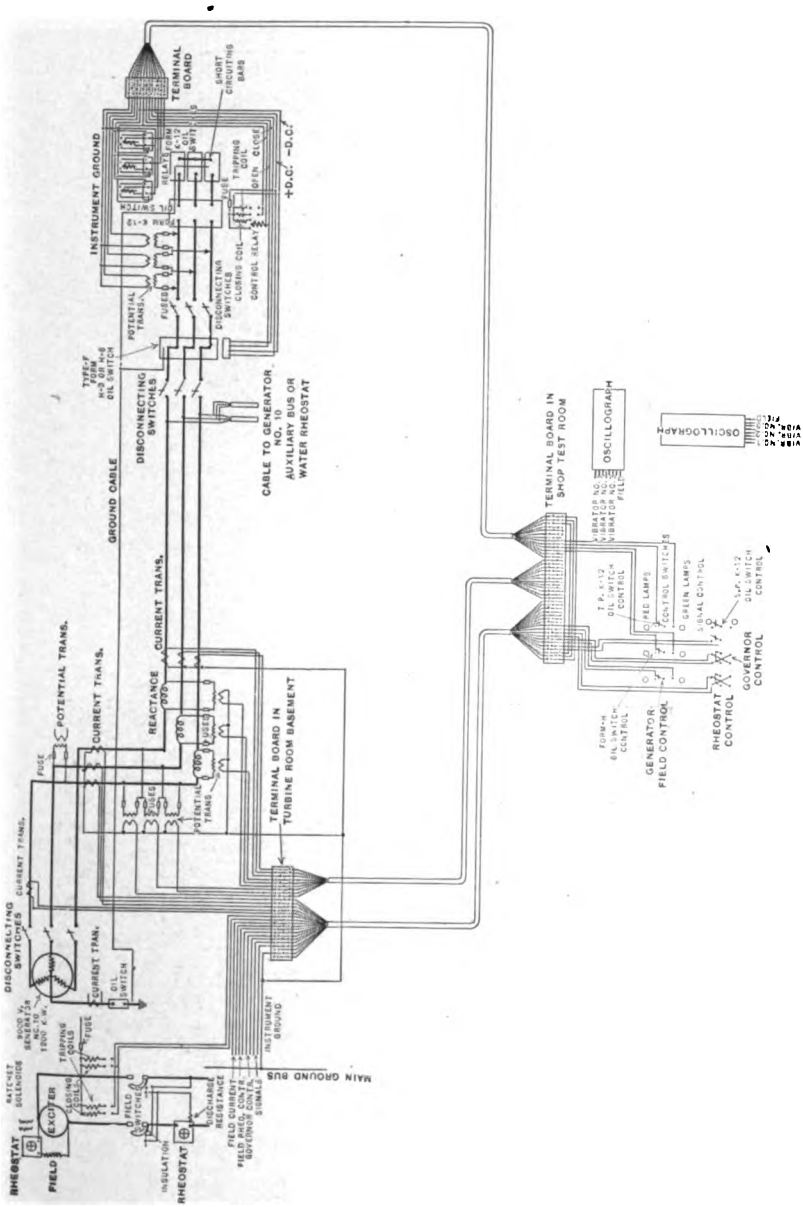


FIG. 3.—Wiring diagram of test circuits

Digitized by Google

The switch under test then automatically opened the circuit, being tripped by instantaneous relays operated from current transformers.

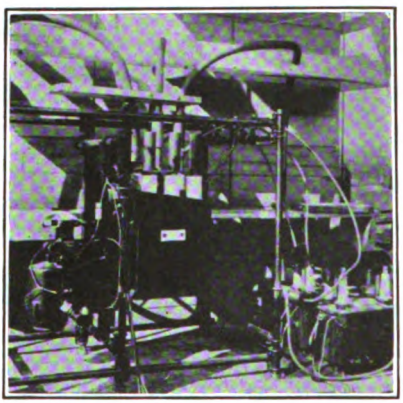


FIG. 4.—Solenoid-operated oil circuit breaker used for throwing on short circuits

OBSERVATIONS

During all the tests, an endeavor was made to note everything of value which occurred and a series of readings were taken as follows:

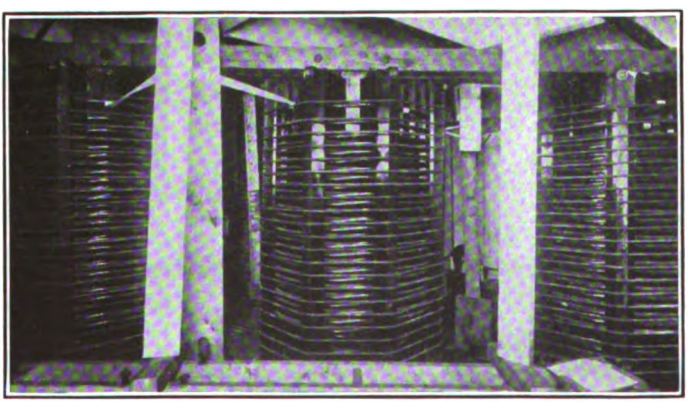


FIG. 5.—Flashlight of generator current-limiting reactances during test No. 27

1. Oscillograms were made showing the relation between the currents and voltages of the various circuits, such as alternator armature current, alternator armature voltage, alternator field current,

Digitized by Google

alternator field voltage, voltage drop across reactances and voltage drop across oil circuit breakers.

2. Pieces of iron of small weight and size, placed at known locations were permitted to be displaced by the stray fields of the reactances in order to indicate the external efforts of these fields.
3. Thin strips of paper were attached to the reactance coils (Fig. 5) in such a manner as to make it impossible for the coils to move without tearing the strips.
4. Spark gaps were placed across the end turns of the reactances in order to detect any voltage rise.
5. Indicator cards were taken to show the stresses developed in the oil vessels of the various circuit breakers during test.
6. The length of arc in the oil circuit breakers under test was measured during test.

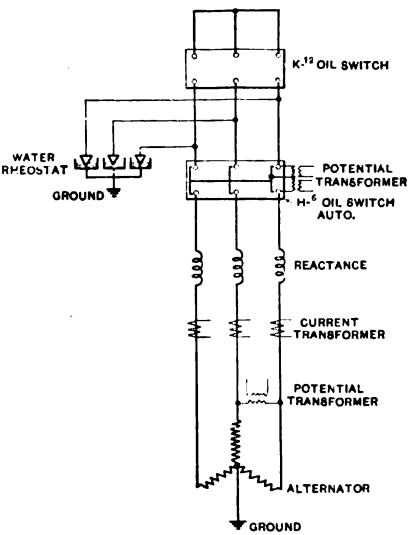


FIG. 6.—Diagram of connections for test No. 27

7. Speed records were taken of the various oil circuit breakers during test in order to permit analyzing the various arc length and pressure records.

TESTS

Approximately 150 short-circuit tests were made during this series and the ones given below have been selected as representative.

Test No. 27. For this test, connections were made as in Fig. 6, the oscillograph vibrators being connected to the secondaries of the current and voltage transformers shown. It will be noted that a water rheostat was connected between the H-6 oil circuit breaker (Fig. 7) and the K-12 oil circuit breaker (Fig. 3). It should also be

Digitized by Google

noted that the reactance in each phase gave a drop of approximately 312 volts at rated load current of the alternator, this being known as a 6 per cent reactance. An initial load of about 7500 kw. was placed on the alternator by the water rheostat and the K-12 oil circuit

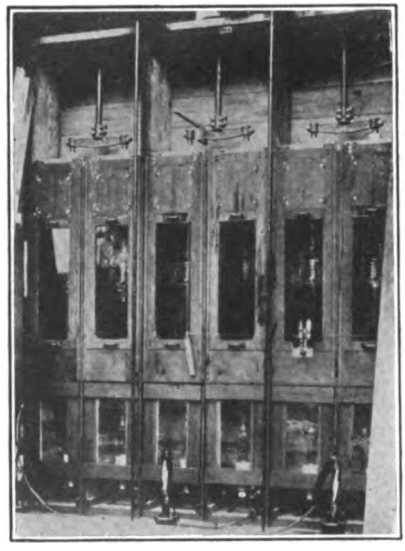


FIG. 7.—Type F form H-6 oil circuit breaker during test No. 27

breaker was then closed, super-imposing a short circuit on the testing system. Oscillograms Figs. 8 and 9 show the events which then occurred and Fig. 10 shows the length of the arc and the stress which was developed near the wall of "A" phase generator oil vessel.

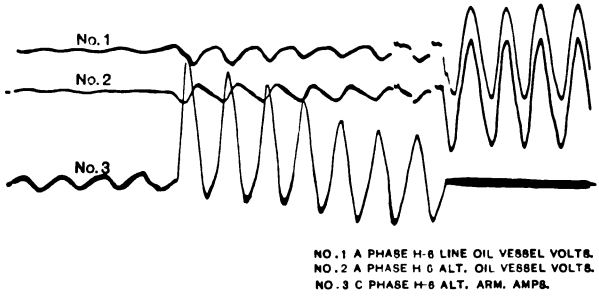


FIG. 8.—Oscillogram A test No. 27

During this test, some smoke came out of the oil vessels and a few drops of oil were drawn up by the switch rods along the inside of the bushings of the oil vessels and splashed out. The reactance windings were not displaced nor did the recording apparatus detect the

Digitized by Google

slightest movement of the coils, although this was one of the worst short circuits recorded.

Test No. 32. Connections for this test are shown in Fig. 11. There was no initial load connected to the alternator and the circuit breaker under test was an H-3 having 8 in. diameter oil vessels fitted with the baffles shown in Fig. 12. As before, the oscillograph vibrators were connected to the secondaries of the voltage and current trans-

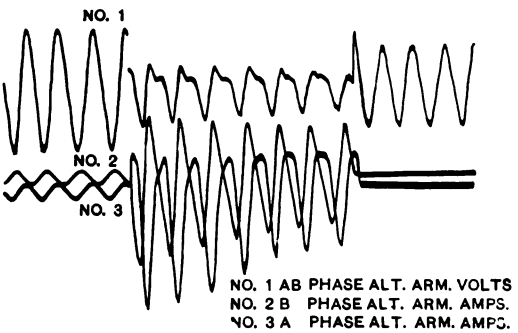


FIG. 9.—Oscillogram B test No. 27

formers and the shunt shown in the wiring. The short circuit was thrown on by the K-12 oil circuit breaker. The resulting oscillograms are given in Figs. 13 and 14 and the stress in the generator oil vessel of " A " phase, velocity of the oil circuit breaker contacts, and the arc length record are given in Fig. 15. Some oil and smoke came out of the H-3 oil vessels during this test. Besides this, the generator oil vessel in " B " phase was distended sufficiently by the

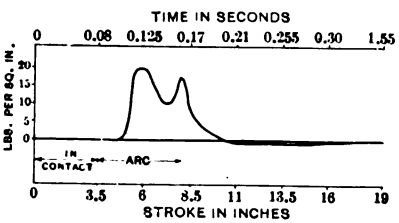


FIG. 10.—Arc length and pressure records test No. 27

pressure developed within it to permit its top to be forced out but without in any way injuring the threads. On examination, it was found that the expansion bolt in this top had not been tightened. The top was then replaced, the expansion bolt tightened and no trouble of this nature was recorded in any of the succeeding tests.

Test No. 61. Connections were made as shown in Fig. 16. The reactance was changed so as to have only 4 per cent in series in each

Digitized by Google

phase of the generator. The H-3 oil circuit breaker was fitted with oil diverters shown in Fig. 17 and as before, the oscillograph vibrators were connected to the secondaries of the current and voltage transformers and the shunt in the generator field. The oscillograms ob-

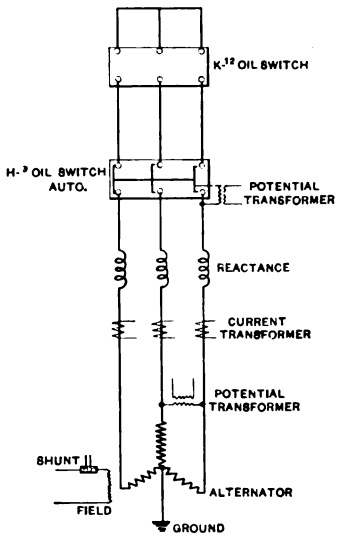


FIG. 11.—Diagram of connections test No. 32

tained are shown in Figs. 18 and 19 and the arc length, stress records, etc., are shown in Fig. 20, the speed curve being developed in Fig. 21. During this test, some oil and smoke came out of the oil vessels of the H-3 switch. Some burning gases came out of the "Cuckoo

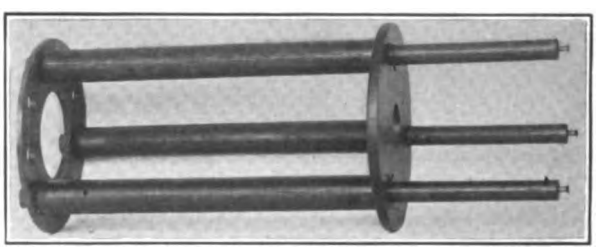


FIG. 12.—Baffle of H-3 oil circuit breaker used in test No. 32

Door of generator oil vessel in "C" phase and it was also noted that the door of this cell opened a little bit.

Test No. 171. Connections for this test were made as in Fig. 23 and 6 per cent reactance was replaced in each of the phases. The triple

Digitized by Google

pole type F form K-12 oil circuit breaker was made automatic and opened the short circuit which was thrown on the system by the three (3) single pole type F form K-12 oil circuit breakers. The resulting oscillograms are shown in Figs. 24 and 25 and the pressure diagrams and arc lengths in Fig. 25. During this test, some smoke and oil came out of the oil vessels but both were directed downward by the external diverters with which this circuit breaker was equipped.

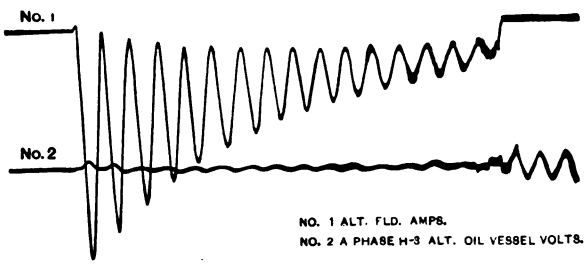


FIG. 13.—Oscillogram A test No. 32

These proved very effective and did not permit the oil and gases to be thrown outward.

Test No. 173. Connections for this test were similar to those shown in Fig. 23. The H-3 oil circuit breaker was made automatic and one phase fitted with an oil diverter. Short circuit was thrown on by the triple pole K-12 oil circuit breaker and the resulting oscillograms are given in Fig. 27, the arc length and stress diagrams being shown in Fig. 28. The action of the H-3 oil circuit breaker

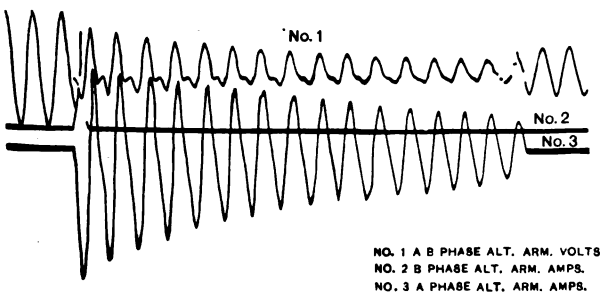


FIG. 14.—Oscillogram B test No. 32

during this test is shown in Fig. 29. It is seen therefrom that some smoke and oil came out of " C " phase oil vessels and some smoke came from " B " phase oil vessels, while " A " phase oil vessels showed no external disturbance. For this test, the " A " phase oil vessels were fitted with oil diverter shown in Fig. 17, " B " phase oil vessels were fitted with a special oil diverter. " C " phase oil vessels were fitted with oil diverter shown in Fig. 12, thus giving a comparison of the action of these three schemes.

Digitized by Google

Effect of Short Circuit on Generator

In tests of this nature, it has always been noted that the field current of the alternator rises when the armature is short circuited. Values as high as ten times field current at rated no

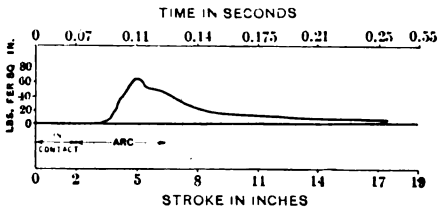


Fig. 15.—Arc length and pressure records test No. 32

load voltage of the alternator were observed during these tests and the form of these field currents is shown in Figs. 13 and 18. This phenomenon is dependent upon the inter-action between

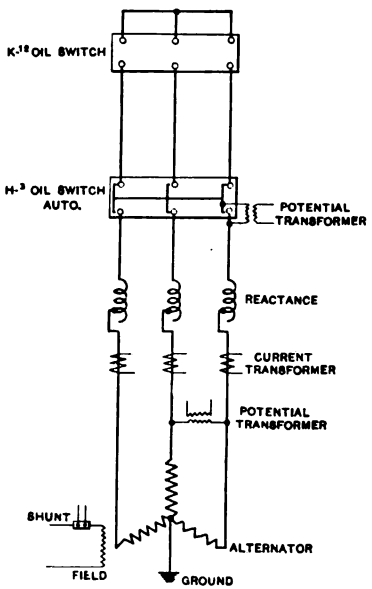


Fig. 16.—Diagram of connections for test No. 61

the field and armature coils, and the maximum value which the field current attains is dependent upon the co-axial relation of the two circuits and their electrical constants. It was also noted during this series of tests that spits of fire came out of the

Digitized by Google

alternator field. This has often been noticed in connection with high voltage transformers suddenly thrown on a live circuit and is doubtless due to the very high voltage induced in the

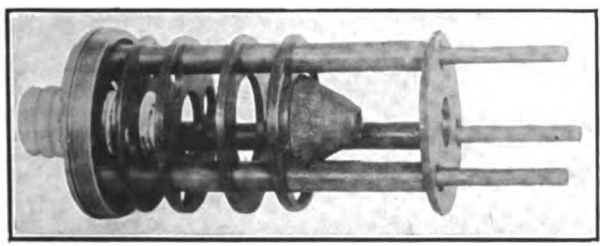


FIG. 17.—Oil diverter of H-3 oil circuit breaker used in test No. 61

alternator field windings when a short circuit current is established in the alternator armature. Our records show that this voltage can be as high as seven times normal, although it may

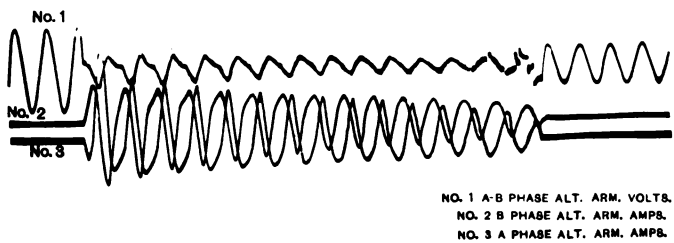


FIG. 18.—Oscillogram A test No. 61

have been considerably higher, since we only made a few measurements.

In some of the single phase tests and also in some of the tests

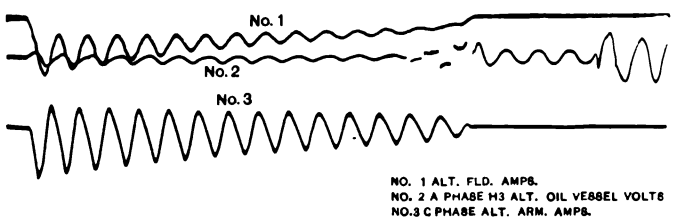


FIG. 19.—Oscillogram B test No. 61

where the short circuit was thrown on by three (3) single pole circuit breakers, it was noticed that the voltage of the phase not short circuited rose to a very high value, some times as high

Digitized by Google

as two and a half times normal. This was probably due to the very large current induced in the field, which, acting on the unloaded phase, produced a voltage rise.

The end turns of the alternator did not move during any of

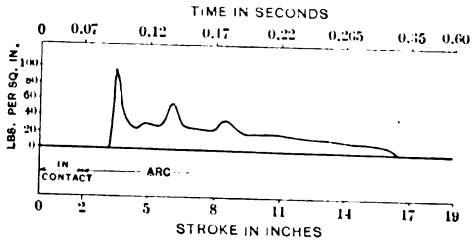


FIG. 20.—Arc length and pressure records test No. 61

these tests, a rigid inspection being made at frequent intervals to detect any such movement.

There was no appreciable drop in the speed of the alternator

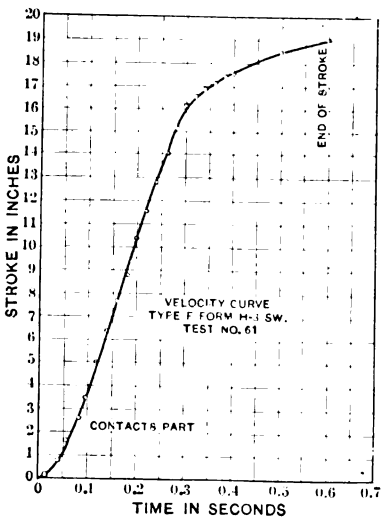


FIG. 21.—Developed velocity curve of H-3 oil circuit breaker taken during test No. 61

when the short circuits were thrown on, probably due to the current limiting value of the reactances discussed later.

In comparative short circuit tests made with the throttle of the turbine open and with the throttle closed, practically the same currents were produced in the test circuit.

Digitized by Google

A number of tests were made by grounding one or all of the three phases of the circuit. In all such cases, it was noted that the effects, as instanced by the action of the oil circuit breaker under test, were very much more violent than when the short circuit was between phases. It was also noted that when the water rheostats were connected to the test circuit as an initial load, their neutral point also being grounded, the effects were very much more violent than when this initial load was absent.

At the completion of the tests, the generator was immediately placed in commercial service and is still operating, none the worse for the severe service demanded of it throughout this series.

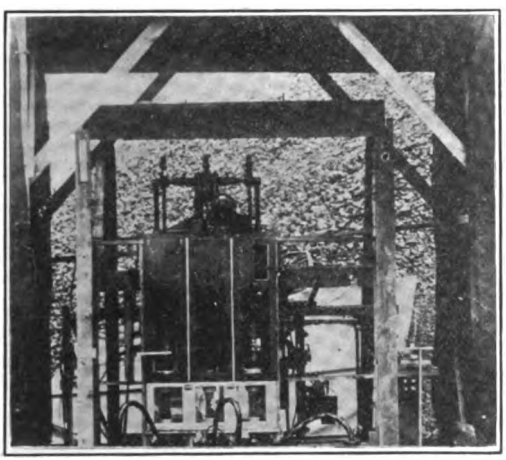


FIG. 22.—H-3 oil circuit breaker opening during test No. 61

This goes far to show the great value of current limiting reactances in diminishing the jar on a generating equipment.

PERFORMANCE OF REACTANCES

The current limiting reactances which were used in these tests consisted of 76 turns of 1,000,000 cir. mil copper cable wound on a cement core and supported by a wooden framework. Each coil was made up in three layers. Terminals were brought out at the top and bottom. The result was a cement cored reactance having no iron in or about it. This construction was employed since the introduction of iron would not appreciably increase the current limiting value of the device. It was also found with the particular generator under test that the introduction of

Digitized by Google

6 per cent reactance in each phase halved the maximum instantaneous current and reduced the torque on the turbine shaft to about one seventh of what it would have been without the reactance. In mentioning 6 per cent reactance, it should be recalled that this refers to the drop across the reactance, which, with rated load current through it at rated frequency, would be 6 per cent of the rated phase voltage of the alternator. The reactances also maintained the terminal voltage of the alternator when a short circuit was thrown on the system beyond the reactances, and permitted the generator to recover its normal voltage

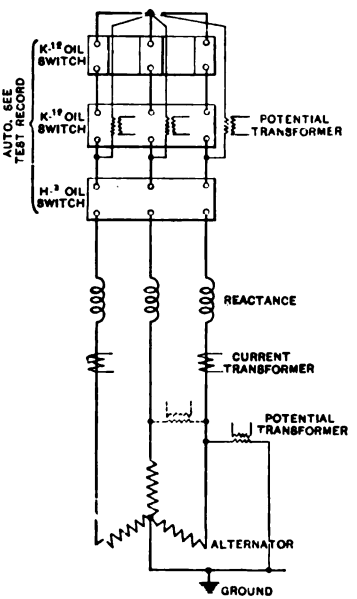


FIG. 23.—Diagram of connections for tests 171 and 173

after a short circuit had been removed much more rapidly than would have been the case had the short circuit been placed directly across its terminals. This makes them of great importance where a synchronous load is connected to a system since one of the two features for holding a synchronous load is the maintenance of voltage.

As a result of the reduction of the torque on the turbine due to the introduction of reactances, there was practically no drop in speed when a short circuit was thrown on it. Hence, the frequency of the system was maintained at practically normal

Digitized by Google

value, and this, together with the maintenance of the alternator voltage, as previously described, tended to markedly improve the operation of synchronous apparatus under abnormal conditions.

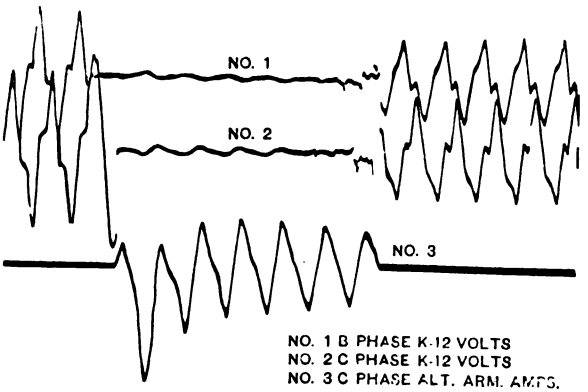


FIG. 24.—Oscillogram A test No. 171

Current limiting reactances also change the power factor of a short circuit and distort the wave form of the system as may be seen on comparing the first parts of curves 1 and 2 in

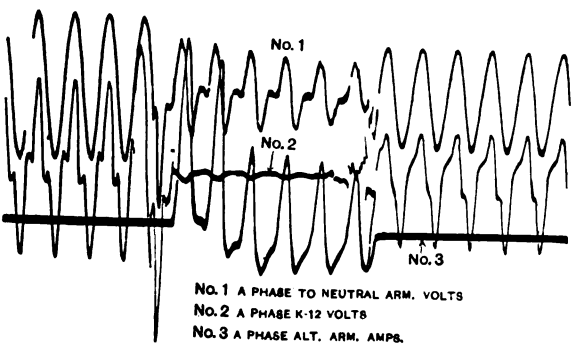


FIG. 25.—Oscillogram B test No. 171

Fig. 25. The stray fields of these reactances were not sufficient to distort the coils in any way and at a distance of several feet, iron screens were not noticeably attracted nor were they appreciably heated.

Digitized by Google

Action of Oil Circuit Breakers

In the discussion of various tests, it was noted that at times some oil was thrown out of the oil vessels. By suitable baffling, the energy imparted to the oil by the expansion and explosion of the gases generated in the oil vessels was absorbed and the operation of the circuit breaking device materially improved and its rupturing capacity increased.

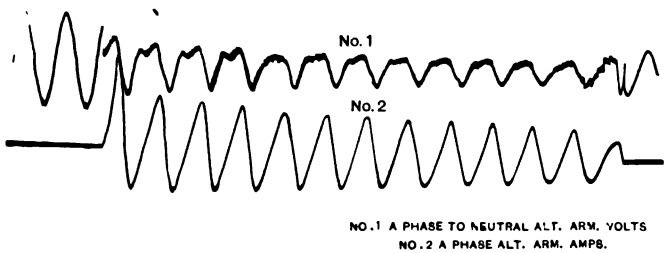


Fig. 27.—Oscillogram test No. 173

It was also found possible to separate the gases from the oil, thereby permitting the gases to escape into the air and the oil to be retained in the oil vessels.

In a commonly constructed design, a small distortion of the oil vessels permits a considerable quantity of oil to be thrown out. This, however, can be readily prevented.

It is very often found convenient to install oil circuit breakers

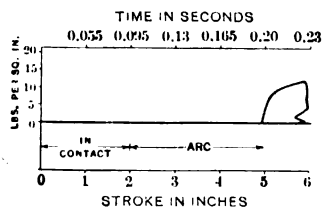


Fig. 26.—Arc length and pressure records test No. 171

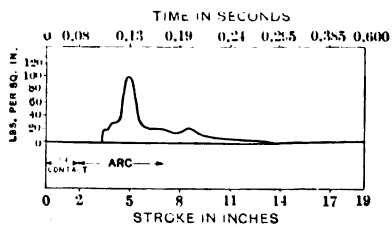


Fig. 28.—Arc length and pressure records test No. 173

in fire resisting compartments. By means of external oil diverters, it was found possible to direct the gases and oil thrown out of the oil vessels to the lower parts of the cells. In reported cases on other systems, gases from oil circuit breakers have been known to ignite, resulting in an explosion. Suitable baffles and diverters can be designed, however, to take care of these conditions.

Digitized by Google

In all of these tests, the temperature of the oil was roughly noted and in no case was it found to have been raised an appreciable amount after short circuit was opened. In some recent tests where successive short circuits were opened by oil circuit breakers (some times as many as six in ten seconds) it was also found that the oil did not heat appreciably. It is thought that this is due to the intensely local action of the oil circuit breaker, for, when the contacts part, the arc which is drawn produces gases which form pockets in the oil.

The larger oil vessels of the H-6 form were of greater assistance

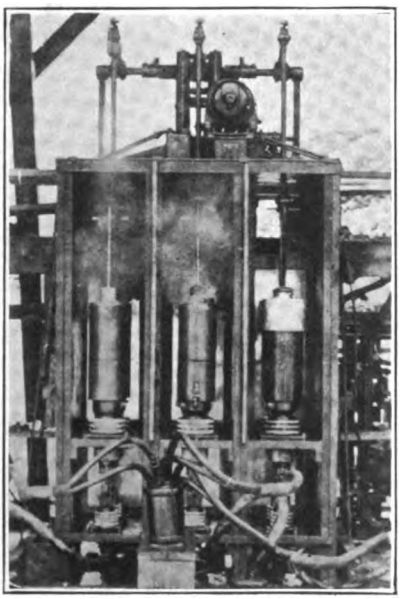


FIG. 29.—H-3 oil circuit breaker opening during test No. 173

in opening a circuit. The results show that the stress developed in the 10-in. diameter oil vessel is only from one-third to one-fifth of that developed in an 8-in. diameter oil vessel of the H-3 form.

It was found that by diminishing the velocity with which the contacts parted, there was more disturbance and the rupturing capacity of the device was greatly diminished.

The length of break is directly connected with the velocity of moving contacts. A long break is very desirable in as much as it gives a large factor of safety under normal operating conditions and a much greater rupturing capacity in emergencies.

Digitized by Google

A preliminary review of these tests shows that the oil circuit breakers opened all of the loads or short circuits without producing any external disturbances or developing any undue pressures, and their ultimate rupturing capacity was not reached. The main current carrying parts were well protected from burning by the arcing contacts and these latter were not materially injured after opening and closing numerous short circuits. The temporary cell structure, although made of inflammable materials, was not injured in any way, and practically no stresses were developed in the cells.

During some of these tests a small quantity of oil came out of the oil vessels, was deposited on the cell doors and spreading out very thin gave the impression of a larger amount. By actual measurements after a number of severe short-circuits it was found that only 5 per cent of the oil had been lost. The repeated use of the oil in the oil vessels did not appreciably diminish its efficiency and the introduction of suitably designed oil baffles and diverters overcame the tendency for the oil to come out of the oil vessels. The oil diverters and baffles experimented with can be readily applied to existing circuit breakers at comparatively small expense and with practically no changes to the original installation.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

DEVELOPMENT OF THE MODERN CENTRAL STATION

BY CHARLES PROTEUS STEINMETZ

The predecessor of the huge modern central station is the Edison direct-current three-wire station, which was developed 20 years ago. By a system of feeders and mains, direct current was distributed at 220-volts from a station located at the center of power demand. When the limit of economical distribution from a single station was reached, additional stations were built, and all the stations connected by tie-lines.

Characteristic of these stations were the good voltage regulation, incident to the system of feeders and mains; the high economy, resulting from the parallel operation of all the stations and the consequent reduction of light load losses to a minimum, and the high reliability of service, which stands unexcelled even to-day, and which resulted from

a. The parallel operation of all the stations, which guarded the system in case of breakdown of one or several stations;

b. The storage battery reserve, which maintained service even at a complete shut down of all the generating stations, and especially

c. The nature of the system of low tension feeders and mains, which limited the effect of any breakdown at any point of the system to its immediate vicinity, by limiting, by the resistance of feeders and tie-lines, the power which could be concentrated at any point, to such an extent, that no local breakdown could involve, or even seriously affect the entire system.

It must be conceded that in this latter respect this low-tension system was safer than even the present modern high-voltage generating systems, and in the latter the problem of the localiza-

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26-30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

tion of the effect of any breakdown is still the most important one in the development of the modern central station.

The most serious disadvantage of the direct current three-wire generating station was the limited distance, to which power could be transmitted economically at 220 volts. This limited the use of the system to densely populated districts, as the interiors of large cities were within the economic radius of 220-volt distribution a load for a generating station of economical size could be found. It also did not permit the best economy of operation, as it required the location of the generating stations in the interior of the cities.

The limitations in the distance of transmissions were soon overcome, and electric power made generally available, by the alternating-current system. As it was first developed, as single-phase high-frequency system with individual transformers at the customers' premises, it had the fatal defect of large all day losses in the transformers, and as the result, most of these early alternating-current stations were not an economical success, and the alternating-current system became economically feasible only by the introduction of the three-wire-secondary mains, fed from large transformers by primary feeders, that is, the main features of the Edison feeder and main system, from which the modern alternating current system differs only by the substitution of high-tension feeder and transformer, for the low-tension feeder of the direct-current system, and by the addition of a fourth wire or other method (as separate feeders), to take care of power distribution to motors.

The final power supply to the customers, for lighting or other domestic services, is now generally from a three-wire 220-volt main, by direct current in the interior of large cities, by alternating current in less densely populated districts. The characteristics which make the direct-current systems suited for more concentrated, the alternating-current system for less concentrated demands, are:

Reactive drop and magnetic screening are absent with direct current, and large conductors can thus be used, carrying larger currents than are economical with alternating distribution. A greater density of load can thereby be taken care of, larger power supplied over each feeder, and voltage regulation at every feeding point in the mains thus becomes economically feasible. The mains, tied together, exchange power between feeders, and thereby equalize the voltage. Storage battery

Digitized by Google

reserve is conveniently feasible, with its great increase in the service reliability. For certain classes of service, as high speed elevators, the direct-current motor is further developed. However, the low-tension direct-current feeder must be carried back to a generating station or converter substation.

With alternating-current supply, 2200-volt high-tension feeders can be used, and a much larger territory thereby supplied from one station. Much lower voltage drops are feasible in the high-tension alternating-current feeders, than in the low-tension direct-current feeders, and several transformers with their secondary mains can thus be supplied, with fair regulation, from the same primary feeder, and this allows the installation of small mains of limited extent. The secondary mains may be sectionalized without serious disadvantage in regulation. The high efficiency of the modern transformer permits economical power supply in districts which can not be reached by direct current, as the load is so scattered that only a moderate amount of power is accessible to each main, and sufficient load for the economical operation of a converter substation could not be found within the economical radius of such a station.

The economic disadvantage of the location of a number of direct-current generating stations in the interior of large cities led to their replacement by converter substations, which receive their power from a large three-phase generating station, usually at 25 cycles. Thus originated the present system of monster three-phase power generating stations, which supply numerous converter substations for 220-volt underground direct-current distribution in the interior of the cities, with storage battery reserve; supply transformer or frequency converter substations for 2200-volt alternating primary distribution in the less densely populated districts, 600-volt converter substations for railway, and supply three-phase 25-cycle power direct to large motors. Reliability insurance against a serious breakdown in the generating station led to the subdivision of the power generation in two or more main generating stations, and so we see now in operation in this country huge generating stations, coöperating with each other and with smaller outlying stations, very similar in principle, though vastly greater in magnitude, than the direct-current three-wire generating stations of 15 years ago. To the former direct-current generating stations thus correspond in the present central station development not the converter substations of the direct-current distribution sec-

Digitized by Google

tion of the system, but the main three-phase generating stations, and to the 220-volt feeders and tie-lines between the stations correspond the 6,600-, 9,000- or 20,000-volt power feeders from the main generating stations to the substations, and the tie-lines between the generating stations.

Comparing the modern system of high voltage three-phase generating stations, which supply power to a large city and almost to a state, with the system of low voltage direct current generating stations of old, we find, besides the vastly greater amount of power of the modern system, and correspondingly greater destructiveness of the power when beyond control, two essential differences:

a. The alternating nature of the power involves in the parallel operation of the generating stations, as required by economy and reliability, the problem of synchronizing, which did not exist with the direct current stations.

b. While in the direct current system the power, which could be developed at any point in the system, was limited by the resistance of feeders and mains, and the limited power of the generators, and an accident anywhere in the system could not seriously involve the entire system, but remained essentially local in character, in the present system the maximum power is available practically everywhere, and an accident or disturbance may be felt over the entire system. That is, the safety resulting from the locally limited power, and corresponding reliability, of the direct-current system, is not inherent in the modern high-power and high-voltage alternating system, and before the operation of the present huge systems can be as safe and as reliable as that of the low-tension direct-current systems was, means must be found to limit the power which can be developed in case of accident anywhere in the system, to a safe value, that is a value which would not seriously affect or endanger the operation of the system.

The safety of the low-tension direct-current system against general disturbances caused by a local accident, such as a short circuit, was the result of the relatively high resistance of circuits; it was however paid for by a lower efficiency of distribution, resulting from the losses in the line, such as are no longer permissible in our modern large systems, and if permissible, would not be feasible, as the distribution cables could not dissipate the power without self-destruction. However, due to the alternating nature of the power, voltage can be consumed in the modern systems, and

Digitized by Google

the current limited thereby, without corresponding loss of power, by reactance; and to make our modern high-voltage high-power systems as safe against local accidents, as were the low-tension direct-current systems, power-limiting reactances must in the former take the place of the resistance of lines, feeders and mains of the latter system.

The industry has been slow to realize the importance of reactance in giving safety and corresponding reliability to high-power generating systems. The reason was a prejudice against reactances, which had survived from the early days of the single-phase high-frequency systems, in which the reactance in generators, lines and transformers had been the enemy which spoiled the desired voltage regulation. We are just beginning to realize now, that in the huge systems which use a large part of their power by synchronous machines, as converters, frequency changers, etc., reactance is not an enemy to regulation, but affords the most effective means of voltage regulation by phase control.

A considerable amount of reactance is necessary for safety, to limit the possible local concentration of power, and for voltage regulation in systems containing synchronous machines, and also for the stability of the latter, as the parallel operation of synchronous machines, whether generators, motors or converters, is possible only if the circuit between the machines contains considerable reactance.

In a station or group of stations of 100 to 200 megawatts generator capacity, in high-speed turbo alternators—and there are a number of such stations now in existence—with a momentary short circuit current of 30 to 40 times full load current, the maximum current which could momentarily appear at a short circuit on the bus bars, would correspond to from three million to eight million kilowatts. When opening such a short circuit, the power at the opening break must pass from zero at short circuit to zero at open circuit, over the maximum momentary output of the generator, which is one-half the product of short circuit current and open-circuit voltage, or from one and one-half to four million kilowatts. It is obvious that no switching mechanism can be designed which can always be relied upon to open such power, and which at the same time is sufficiently small and reasonable in cost, to employ hundreds of them in the system, on the generators, feeders, etc. Hence the insertion of power-limiting reactance in generators, busbars, etc., becomes necessary for the safety of the system.

Digitized by Google

The low-tension direct current generators of old probably gave a momentary short circuit current of three to five times full load current, and at permanent short circuit lost their excitation. The modern high efficiency turbo-alternator gives from three to five times full load current on permanent short circuit, but nearly 10 times as much momentarily. While the permanent short circuit current is within safe limits of the mechanical and electrical strength of modern apparatus, the momentary short circuit current is not, but, allowing for the advance in the art of machine design since the days of the low-tension direct current machine, a momentary short circuit current of 10 to 12 times full load current would be within safe limits. This means increasing the self-inductive reactance of the generator to 8 to 10 per cent. It can either be done by the insertion of external reactance, preferably in the phase leads, or by the design of the generator, or by both. Internal reactance of the generator of the required amount interferes with economical design, and has the disadvantage of offering no protection in case of an internal short circuit which eliminates the generator reactance, and the preferable method thus is to give the generator a reasonably high internal reactance (3 to 5 per cent) and insert additional reactance in the phase leads, of 4 to 6 per cent* Where step-up transformers or auto-transformers are used, they can be designed to afford the required external reactance.

Even when limiting the momentary short-circuit current of the generators to 10 times full load current, with the parallel operation of a system of several hundred megawatts generator capacity, the momentary short circuit power would still approach millions of kilowatts. It therefore becomes necessary in these large systems, either to operate the system in a number of separate sections, or to sectionalize the busbars by power limiting reactances.

The former is frequently done, but appears to me a temporary expedient only, and economically impracticable as a permanent condition of operation. When limiting the generator capacity per section to a maximum of 60 megawatts, three or four sections would be required in some of the existing systems. As this

*These power-limiting reactances must maintain their reactance at short circuit. Thus, if iron is used in them, the densities must be so low that saturation is not reached with the short circuit current. With a 4 to 6 per cent reactance, this limits the iron density to $B = 500$ to 1000, and as such low densities can far more economically be produced in air, the power-limiting reactances are ironless reactances.

Digitized by Google

means a partially loaded generator in every section, a larger total generator capacity is required, and a lower economy of operation results, than with parallel operation of the entire system. Furthermore, reliability would require to supply every substation from several sections, and this would necessitate to sectionalize also every substation on the alternating side, and would thereby lower the economy of the use of feeders and substations. The necessity of providing means of throwing substation apparatus from one section to another section, in case of accident to one section, complicates the method of control and introduces the danger of accidentally connecting together in the substation feeders coming from different sections and out of synchronism with each other, with the result of a short circuit between two sections. As the complication of control would usually make it impracticable to carry feeders from more than two sections into a substation, the reliability of service would be lower than in parallel operation, when important substations could receive power from three or more power houses. The loss of economy and of reliability, and the complication of control of the system increase so rapidly with the increasing number of separate sections, that it appears to me, that the only feasible method, which permits unlimited extension of the system without any increase of danger and complication, is the parallel operation of the entire system, on a single ring bus, which is divided into sections by power limiting busbar reactances.

These reactances must be large enough to limit the power which can flow over them, so that in case of a short circuit on one section, the adjoining busbar sections are only moderately affected, the further busbar sections not affected at all; at the same time, the reactances must be sufficiently low and of sufficient capacity, that any amount of current, which during a change of load a busbar section may draw from the adjoining busbar section, can be safely transmitted over the reactance without any voltage drop, by a slight phase displacement between the adjoining busbar sections. With a capacity of 50 to 60 megawatts per section, a permanent carrying capacity of each busbar reactance, of two megavolt-amperes, at 15 deg. phase displacement, and a power limit, in case of a short circuit on one section and full voltage on the adjoining section, of 40 megavolt-amperes appears at present the best compromise. The ring bus, into which all the generators G of the system feed, would then comprise the busbars B of the various power houses, II_1, II_2 ..., and

Digitized by Google

the tie-lines L between the power houses, as indicated diagrammatically in Fig. 1, in which x denotes the power-limiting reactances in the generator leads, x' the power-limiting busbar reactances, F the feeders which issue from the busbar section, and C denotes the non-automatic, $A\ C$ the automatic circuit breakers in the system.

Coming now to the consideration of the feeders which issue from the generator busbars. In the low-tension direct current system, the effect of a short circuit in a feeder—if not extremely

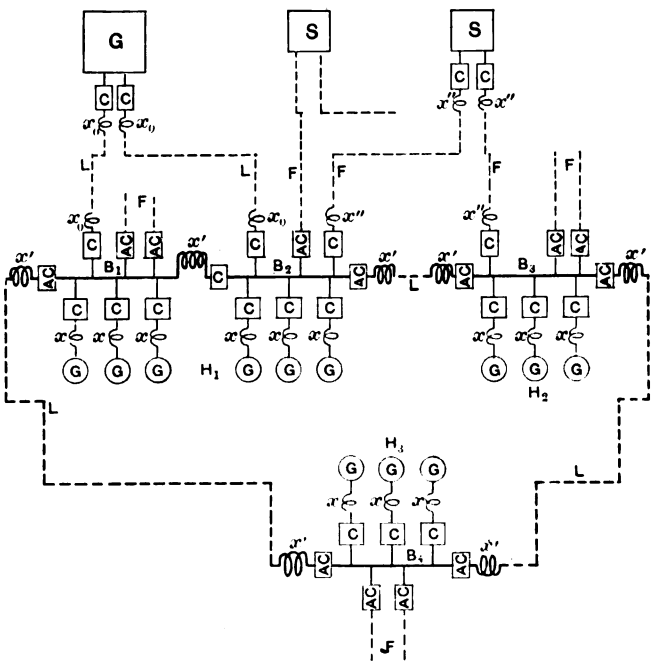


FIG. 1

close to a generating station—was limited by the resistance of the feeder. With the modern high-power alternating system, the feeder resistances are very low, and a short circuit in a feeder is almost a short circuit on the busbar. While generator reactances and busbar reactances greatly limit such a short circuit, there still remains the disadvantage, that nothing limits the power which is available locally on a feeder, below that available on the busbar to which the feeder connects, and in this respect the modern system is inferior to the old low-tension direct-current system. The safest method would be to limit

Digitized by Google

the available short circuit power of every feeder by reactances at either end of the feeder, in the generating station and in the substation S, as indicated by x'' in Fig. 1. This method, which would make the modern high-power system as safe as the former low-tension direct-current system, has not yet been considered, since unfortunately the development of the alternating part of the present system has started from the experience of the small alternating systems of old and not from that of the low-tension direct current system, and in the former, the limited power of the generating system, combined with the relatively high reactance of the overhead feeders, made power limiting reactances in the feeders unnecessary. Instead of limiting the power, automatic circuit breakers are provided in the feeders, as indicated by A C in Fig. 1, which instantaneously cut off the feeder in case of short circuit. This method has been very successful, and with the limitation of power by the reactances in busbars and generators, appears sufficiently safe, but still has the disadvantage of momentarily exposing the busbar section and the feeder switches to the shock of short circuit in case of a failure of the feeder, and it may thus well be considered, whether a safer way of operation would not result from limiting the power of the feeders by reactances and then hold on to the feeder in case of a fault, until the fault either clears itself, or the feeder has to be cut off, that is, in other words, to return, even in this last structural element of the modern station, to the well tried principle of the low-tension direct-current system.

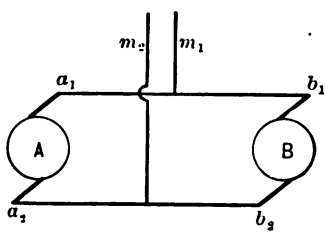


FIG. 2

In the parallel operation of the individual generators, and the entire generating station of the modern high voltage alternating-current system, a problem is involved, which did not exist in the direct-current system, *viz.*, synchronizing. The general problem of synchronous operation is well understood and is as follows:

If two machines, A and B in Fig. 2, (whether generators, synchronous motors, converters or frequency changers) shall run in synchronism, the constants of the circuit between the two machines, a_2 a_1 b_1 b_2, must be such that any phase displacement (that is, position displacement) of the two machines causes a current to flow between the machines, which accelerates the

Digitized by Google

lagging, retards the leading machine, irrespective whether in addition to exchange or cross current between the machines, the machines also send out current, or receive current from the outside, at m_1 m_2. If the two machines are exactly in step, in the local circuit a_2 a_1 b_1 b_2, the voltages of the two machines, are in opposition, as shown by a and b in Fig. 3. Thus there is no resultant voltage, and no current flowing between the machines. If now the two machines are slightly out of step, and B lags slightly, that is, its voltage reaches the maximum at a slightly later time, b in Fig. 4, and A leads slightly, that is, its voltage reaches the maximum at a slightly earlier time, a in Fig. 4, the two voltages a and b in Fig. 4 give a resultant, which reaches its maximum midway between a and b, as shown as c in Fig. 4. This resultant or cross voltage of the two machines produces a cross current circulating between them. If now the circuit

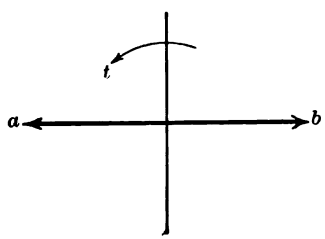


FIG. 3

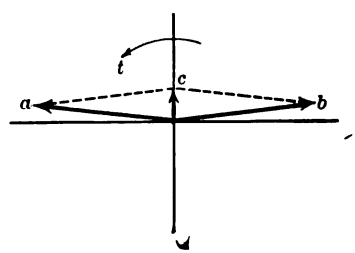


FIG. 4

between the two machines, a_2 a_1 b_1 b_2, should contain only resistance, but no reactance, the cross current i would be in phase with the cross voltage c, as shown in Fig. 5. It would then be practically in quadrature with the two machine voltages a and b, that is, would be a wattless current in the two machines, neither consume nor produce power, that is, there would be no synchronizing power.

Assume now that the resistance of the cross circuit is negligible compared with the reactance, then the cross current i would lag nearly 90 deg. behind the cross voltage c, which produces it, as shown in Fig. 6. Thus it would be approximately in phase with a, approximately in opposition with b, and would thus consume power in the leading machine A, that is, retard it, and supply power to the lagging machine B, that is, accelerate it, and thus pull the two machines together, as synchronizing current. Hence, the reactive or quadrature component (with regard to the

Digitized by Google

cross voltage c) of the cross current is the synchronizing current, and the power component of the cross current exerts no synchronizing power. Thus, reactance is necessary for synchronous operation, and the larger the reactance is, compared with the resistance of the cross circuit, the larger a part of the cross current is synchronizing current. Increasing reactance therefore increases the synchronizing power. There obviously is a limit hereto: with increasing reactance, the cross current decreases, and while the percentage of the cross current, which is synchronizing current, increases, the absolute value of the synchronizing current, and with it the synchronizing power, again decrease.

For stable parallel operation of synchronous machines, a reactance of the cross circuit thus is required, which should be at least twice the resistance of this circuit.

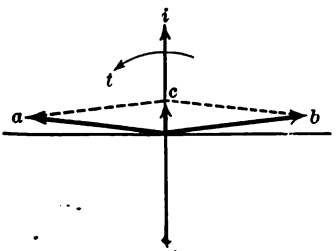


FIG. 5

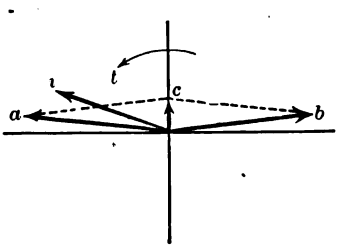


FIG. 6

Of the synchronous reactance of an alternator, essentially only the true or self-inductive component comes in consideration in synchronous operation, as the armature reaction component is usually too slow to exert itself. In steam-turbine alternators, the self-inductive armature reactance is very low, frequently only 2 to 3 per cent; however the armature resistance is a fraction of one per cent, and when connected to the same busbars, synchronous operation of such generators is satisfactory. A few per cent of resistance between the turbo alternators, as may exist when operating two power houses together over a tie-line, makes synchronous operation unstable or impossible without the insertion of a corresponding amount of reactance. This is to be kept in mind in the parallel operation of power houses, the more as the tie-lines are usually underground cables, and as such have practically no reactance. With power-limiting reactances in the generator leads, obvi-

Digitized by Google

ously a much higher resistance in the tie-lines between power houses would be permissible before parallel operation becomes impaired and additional reactance is required.

Parallel operation of synchronous machines thus requires reactance in the circuit between the machines. It is further required, however, that the combined effect of resistance and reactance, that is, the impedance of the cross circuit, is sufficiently low to allow a large enough current to flow to keep the machines together against any tendency which separates them, as inequality of the driving power, slighly different speed adjustment of the engine governors, etc. That is, the possible cross current between the machines must be comparable in magnitude with their full load current. This however is frequently not possible in the parallel operation of power houses distant from each other, over tie-lines. The capacity of the tie-lines between big power stations would economically be proportioned to the required exchange of power, and thus usually would not be sufficient to pull the two stations together into synchronism. Here, then, a new problem arises which was not met previously in synchronous operation of alternators: the engine or turbine speeds of the two stations must be controlled, independently of the alternators, so as to be so closely the same under all conditions, as to require a very small synchronizing power between the alternators, to pull into step and remain in step. That is, as we may express it, the prime movers must be synchronized. While this had not been done before, it is a mechanical problem, which electrically can be solved without serious difficulty, for instance, by controlling the governor in the steam supply by the power exchange between the stations, in combination with sufficiently powerful dash-pots, to guard against governor hunting.

An important application of this problem of electro-mechanical synchronizing will occur in the parallel operation of outlying stations, with the main station.

For instance, if at the end of a long feeder the power demand increases so greatly as to warrant the installation of a moderate sized station—one or two 2- to 5-megawatt turbo alternators—economy and reliability of operation would require this outlying station to be paralleled with the main generating station, so as to use the main station as reserve; and the economical method of operation would be to run the outlying stations as nearly at constant full load as possible, and take care of the

Digitized by Google

load fluctuations by the main station, over the tie-lines, to get the benefit of the diversity factor of the entire system. This usually means not only a fluctuating flow of power in the feeder from the main station to the outlying stations, but often also a reverse flow. Voltage regulation at the outlying stations then can be accomplished only by phase control of the feeder, through reactances, as indicated at X_0 in Fig. 1, and with the increase of the outlying load the feeder capacity very soon would be insufficient to pull the outlying stations into step, and mechanical synchronizing, as discussed above, becomes necessary. We must realize, that in the direct line of the modern central station development is an extension of the power supply to that of an entire state or a number of states, from a few huge main stations near the centers of power demand, and numerous smaller outlying stations, with the entire system operating in synchronism through feeders and tie-lines, in which the power flow fluctuates in amount and in direction, and of which very few are sufficient to pull stations together into synchronism, but just sufficient to keep them in synchronism, if the speed regulation of their prime movers is independently maintained very closely the same.

These then are the two problems before the modern central station: The localization of any disturbance by power limiting reactances, and the synchronous operation over lines of limited power, by speed control of the prime movers.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.
(*Subject to final revision for the Transactions.*)

THE COMMERCIAL LOADING OF TELEPHONE CIRCUITS IN THE BELL SYSTEM

BY BANCROFT GHERARDI

The year 1900 may be considered to have marked the beginning of a very important period in the development of telephony. For some time prior to that date it had been known to those who gave study to the matter that the transmission efficiency of long telephone circuits would be improved by increasing the uniformly distributed inductance of the circuit. This knowledge, however, did not lead to any direct commercial results for the reason that no one was able to point out any practical method of increasing the distributed inductance of a telephone circuit without bringing in difficulties of one kind or another which were fatal.

This apparently insuperable difficulty in obtaining improved results by the use of distributed inductance directed the attention of the mathematicians and physicists to the question of whether the results sought for might not be attained by the use of inductance coils placed at intervals in the circuit instead of by undertaking to distribute the inductance uniformly along the circuit. Vaschy, Heaviside and others either suggested or unsuccessfully tested the insertion of self-induction in coils on actual lines as a means of increasing their transmission efficiency. No practical results followed from their work and no actual progress was made in the matter of using lumped inductance to improve the transmission efficiency of telephone circuits until the year 1900, when the patents of Professor M. I. Pupin, dealing with the reducing of attenuation of electrical waves,

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

were issued. Professor Pupin,[1] and Dr. George A. Campbell,[2] who had also worked on this problem, have published several papers dealing with it. These authors discuss fully the mathematical theory of improving the transmission efficiency of telephone circuits by means of placing thereon inductance coils at intervals. The papers referred to establish the fact that inductance in coils spaced suitably along a telephone circuit will produce the same effects as uniformly distributed inductance and show us how to suitably locate these inductance coils. The matter of suitably spacing the inductance coils is of vital importance and must be kept in mind because the spacing of the inductance coils is the key to the use of lumped inductance and it is from the failure to establish this fact and give due weight to it that the earlier workers failed.

I shall not undertake here to go over the theoretical ground which has already been so well covered in the papers referred to, but before describing some of the practical applications of loading to open wire lines and cables, and discussing the results which have been obtained and mentioning some of the difficulties which have been overcome, I will state the results of the fundamental work on this question for those who do not care to follow through the mathematical papers on this subject.

In the study of any telephone line, with reference to its efficiency as a means of transmitting speech, two important factors must be considered. These we ordinarily characterize as "volume" and "quality."

Volume refers to the loudness of the sound which may be obtained from the telephone receiver at the distant end of the line, and the efficiency of the line as regards this factor is determined by the ratio of the amount of energy received at the distant end of the line to the amount of energy put into the line at the transmitting end.

Quality refers to the clearness of the speech which may be obtained from the current at the receiving end of the line. The efficiency of the line as regards quality is determined by the degree that the shape of the current wave at the receiving end of the line approximates to that of the current wave impressed upon

1. Transactions of American Mathematical Society, page 259, July, 1900; TRANSACTIONS of A. I. E. E., XVII, May, 1900; TRANSACTIONS of A. I. E. E., XV., March, 1899; Electrical World and Engineer, October 12, 1901, page 587.

2. Philosophical Magazine, March, 1903.

Digitized by Google

the line at the sending end. A line which would transmit all the frequencies concerned in the telephonic current with equal attenuations of all these frequencies and with the same velocity would transmit without distortion, and its quality might be considered to be perfect.

For the present I will confine my attention to the matter of the volume of speech transmitted. The formula for the attenuation of a telephone circuit, excluding the effects of terminal conditions which react on the portions of the line near the ends, is

$$\alpha = \sqrt{\tfrac{1}{2}\sqrt{(R^2+p^2L^2)(S^2+p^2C^2)}+\tfrac{1}{2}(SR-p^2LC)} \qquad (1)$$

in which the symbols have the following significance:

α = attenuation constant per unit length.
R = resistance " " "
L = inductance " " "
C = capacity " " "
S = conductance " " "
$p = 2\pi$ (frequency).

This attenuation constant is a measure of the efficiency of the line, for on any line if the amount of current impressed on it at the sending end is known, and the attenuation constant is known the amount of current at any point along the line may be determined by the formula

$$i = I\, e^{-m\alpha} \qquad (2)$$

in which i = the current at any point;
I = the initial current, and
m = the distance from the initial point of the line to the point at which the current (i) is to be ascertained.

Equation (1) may be simplified somewhat by making

$$S = 0,$$

as this item S representing leakage and dielectric dissipation, is always made as small as is commercially practicable and is, in most cases, sufficiently small to be negligible in its effect upon the general result obtained. With this simplification, equation (1) becomes

$$\alpha = \sqrt{\frac{pC}{2}(\sqrt{R^2+p^2L^2}-pL)} \qquad (3)$$

Digitized by Google

An examination of this equation shows that the attenuation constant will be reduced as the inductance of the circuit, L, is increased. I have already mentioned the fact that no satisfactory commercial method has been suggested or devised for uniformly increasing the inductance. The result of the work published about 1900 shows us, however, that we can obtain the same favorable effects by placing suitably spaced lumped inductance in the circuit as would be obtained from uniformly distributed inductance without the fatal difficulties encountered in endeavoring to place any considerable amount of distributed inductance. This work shows us that if more than π inductance coils per wave length are placed upon a telephone circuit the effect of these coils will be approximately the same as the effect of an equal amount of inductance uniformly distributed along the circuit. If less than π coils per wave length are placed the results are unfavorable. As the number of coils per wave length is increased above π the effect very rapidly approaches the effect produced by uniformly distributed inductance so that if as many as six coils per wave length are placed on the circuit the effect of the inductance thus placed is within 4 per cent of that of uniformly distributed inductance. The wave length in a telephone circuit is easily computed by the following formula:

$$\frac{2\pi}{\sqrt{\frac{1}{2}\sqrt{(R^2+p^2L^2)(S^2+p^2C^2)}-\frac{1}{2}(SR-p^2LC)}} \qquad (4)$$

in which the symbols have the same meaning as in (1) above. To apply this formula to a circuit which it is proposed to load, it is necessary of course to take account of the reaction of the inductance which is to be added to the circuit in the form of loading coils, because this inductance affects the wave length. Therefore, the inductance value in the formula given above must include the proposed loading. In order that all frequencies which are of importance in connection with the transmission of articulate speech shall be cared for by the proposed loading, the frequency employed in this formula must be the highest frequency which takes a necessary part in the clear transmission of speech. It is not found that it is necessary that this spacing of the loading coils should be absolutely uniform. It is important, however, that the spacing should not depart substantially from uniformity.

Without undertaking here to give the equations dealing with

Digitized by Google

the effects of loading on the quality or clearness of speech, it may be stated that it is found both mathematically and experimentally that loading makes the attenuation more nearly equal as between the different frequencies which are important in connection with speech transmission and that loading, therefore, increases the clearness of such speech and improves the quality of the line, particularly on underground cable circuits where, on account of the relatively large amount of capacity in relation to the other characteristics of the circuit, the quality without loading is noticeably inferior on long circuits.

Broadly speaking, it may be stated that what we have done in applying loading to long telephone lines is to adopt the necessary measures to enable us to obtain the advantages of a high potential transmission system, that is, of transmitting the electrical energy from the sending end to the receiving end of the line with a high voltage and a small current as compared with the smaller voltage and higher current which is found on unloaded lines. That this is the result which we are actually accomplishing by loading our lines is shown not only from the study of the equations dealing mathematically with the propagation of telephone currents over loaded and unloaded lines, but it is also further established by actual studies and tests on working lines. We have, therefore, broadly speaking, taken the same step which electric light and power people have taken to improve the efficiency of their long lines. On account, however, of the very different electrical characteristics of telephone lines and currents and high tension electric light and power lines and currents the means which it has been necessary for us to adopt to accomplish this result have been very different from those adopted by the electric light and power engineers.

In the case of power which is to be transmitted at relatively low frequencies, usually 66 cycles a second or less, over lines of relatively short length, say, cables 10 miles long and open wire circuits 100 miles long, it is sufficient in order to transmit the energy with a high voltage and a small current to arrange the receiving end of the line by means of a transformer or otherwise so as to give a great reactance, and to place high potential apparatus at the sending end of the line. Electrically the line is so short that the reactance at the receiving end may be considered to be working directly against the high potential generating apparatus at the sending end and hence the desired result is obtained. With the telephone current, however, which

Digitized by Google

is of high frequencies, and telephone lines which are often very long, the situation is entirely different. Increased reactance placed at the receiving end of the line does not make itself substantially felt at all at the sending end of the line. To obtain the proper reactance for high potential sending apparatus to work against, it is necessary, therefore, in the case of telephone lines to distribute the reactance along the line.

The electrical characteristics of open wire lines and of telephone cables are substantially different from each other. The following table gives the constants of two typical telephone cables and of a typical open wire line:

Type of circuit	Cable	Cable	Open wire
Loop resistance, ohms per mile	88	28	10.5
Mutual capacity, microfarads per mile	0.07	0.07	0.008
Inductance, henrys per mile	0.001	0.001	0.004
Insulation resistance, megohms per mile	500+	500+	1 to 100

The essential differences between the characteristics of these circuits, from the point of view of loading, will be seen by examining the figures in the above table. In the case of underground cable, the capacity is relatively high and the inductance, on the other hand, is relatively small. On overhead lines, however, the capacity is relatively small and the inductance of the circuit, even before it is loaded, is not negligible. The insulation of cables is constant while that of aerial lines varies with the weather conditions. On account of these differences in the electrical characteristics of these two types of circuit the design of the loading coils used on them, the proper spacing of the loading coils, and the results obtained from loading are somewhat different in the two cases. The principles employed are the same in both cases, but the different characteristics of the lines bring about in the loading different dimensions both electrical and mechanical.

The problem of loading underground cables is as a whole easier than that of loading open wire lines and will, therefore, first be discussed.

Loading Telephone Cables

At the present time we are making very general use of two styles of loading for telephone cables, one of which is characterized as "medium" loading and the other "heavy" loading.

Digitized by Google

In a few cases a third style of loading, known as " light " loading, is employed. These three styles of loading differ in the amount of inductance placed upon the lines and hence in the improvement in transmission obtained from the loading. The heavy loading, as the term would suggest, places the greatest amount of inductance on the line and requires coils placed at closer intervals. This heavy loading employs about 0.2 henry per mile and the spacing between coils is about $1\frac{1}{4}$ miles; medium loading provides 0.1 henry per mile with the coil spacing of about $1\frac{3}{4}$ miles; light loading employs 0.05 henry per mile with a spacing of about $2\frac{1}{2}$ miles. The coils for these various loadings are made up on similar cores so that the coils differ only in reference to the windings placed thereon. A description of the coil em-

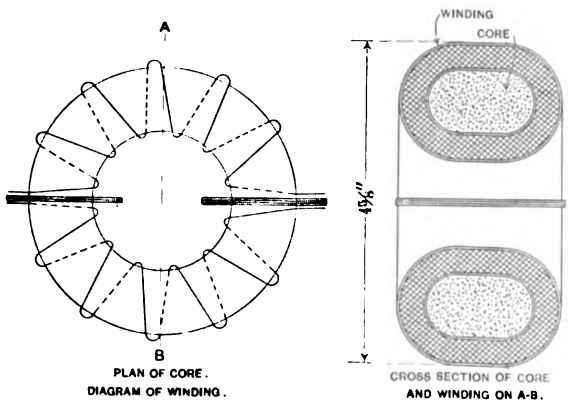


FIG. 1.—Cable loading coil

ployed for medium loading and the method of applying it to the lines is as follows:

The coil is of the toroidal type, that is, it has an iron core like a ring. Fig. 1 shows a cable coil. The core is made up of very fine iron wires. Two copper windings are placed on the core, one to go on each side of the line. These windings are also indicated on Fig. 2 which shows the way the coils are connected in to the line. The windings magnetize the core in the same direction, that is, the mutual induction is added to the self-induction. Over these windings there is placed a layer of tape for mechanical protection and the whole coil is then thoroughly dried and immersed in a compound to keep out moisture.

Before leaving the design of the coil it is interesting to consider

Digitized by Google

the precautions which are taken to reduce losses in it. This is a very important matter as, while the inductance added to the circuit by the coil produces an improvement in the transmission efficiency of the circuit, any loss of energy in the coil means, of course, a reduction in the efficiency of the circuit, and ith poorly designed coils it would be easily possible to bring in losses so large that they would over-balance all the gain from the loading and leave the circuit poorer than before. These losses must be particularly guarded against because they are cumulative.

The first loss to be considered is a dissipation loss resulting from the resistance of the copper winding of the loading coil itself. This loss cannot be entirely eliminated, but it may be reduced as much as may be desired by increasing the cross-section of the winding. There are, however, practical limits to this, as the increase in the size of the winding increases all the mechanical dimensions of the coil and also tends to increase certain other losses.

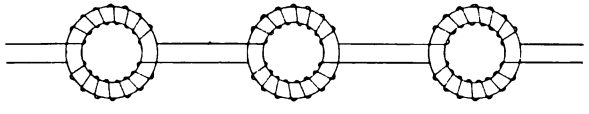


FIG. 2.—Diagram of loading coil windings and method of connecting into a line

A second possible loss in loading coils may also develop in the copper winding. If the cross-section of the conductor used for winding the coil is large, eddy currents may form within the conductor itself and these would produce substantial losses.

Practically this factor is small in cable loading coils, but in open wire coils where a conductor of greater cross-section must be employed it has been found necessary to strand this conductor and to insulate the various strands from each other.

In the iron core of the loading coil there are also several possible losses. In the first place, there is the hysteresis loss. After a great deal of work it has been found practicable to obtain special grades of iron which when worked within certain limits of magnetization are substantially free from hysteresis losses. This at once imposes a limitation on the design of the loading coil and affects the proportioning of all of its parts.

Another loss which may take place in the core of a loading coil is that due to eddy or Foucault currents which may develop in

Digitized by Google

the material of the core itself. In the case of loading coils it has been necessary to construct the cores of extremely fine wire and to coat this wire with a film of insulating material.

Certain other losses must also be guarded against. If a loading coil when magnetized gave an external magnetic field and there were any conducting materials in this field, eddy currents would be produced in this conducting field and would represent a loss of energy through the circuit. Similarly, if there were any iron or other magnetic substances in this field there would be likely to be hysteresis losses in this iron. These losses have been

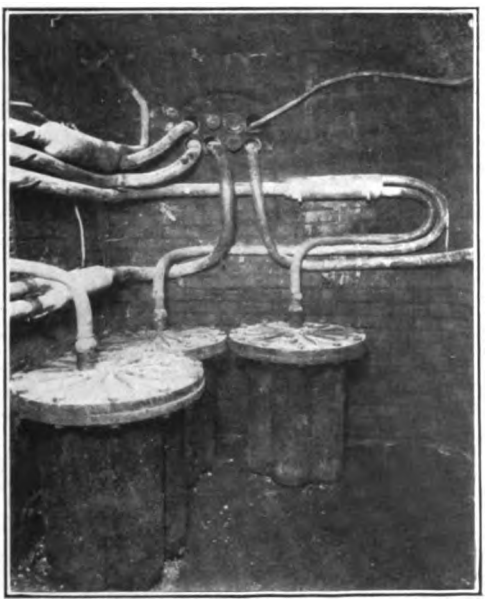


FIG. 3.—Underground man-hole containing loading coils

guarded against by adopting the toroidal form of coil already described and placing the windings on it in such a manner that practically no external magnetic field is in any case produced. The designing of loading coils in this manner has not only eliminated external losses but makes it possible to place loading coils in close proximity to each other without introducing cross talk between the circuits involved. It is interesting to consider that in as far as the losses in loading coils is concerned they very closely resemble the losses which must be guarded against in the construction of, for example, dynamo armatures in electric light and

Digitized by Google

power practice. The resemblance, however, stops at this point and the experiences of electric light and power people in connection with these losses have not been of great assistance in the design of loading coils because the magnitude of current, its frequency and other characteristics have been so different from those involved in electric light and power practice. The great importance of reducing losses, which from the nature of loading are cumulative in character, has made the problem very different.

The direct current resistance of the medium loading coil is about four ohms. The alternating current resistance of this coil, at a frequency of about 800 periods a second, is about nine ohms. This relatively small increase of resistance at such a

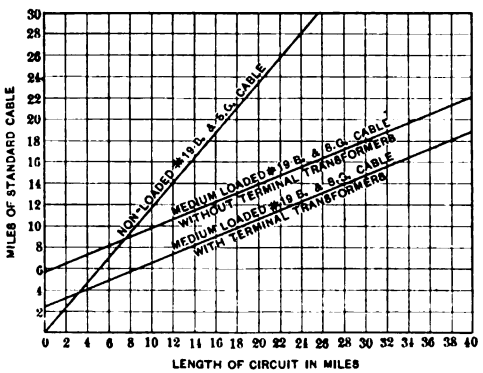

MILES OF STANDARD CABLE
LENGTH OF CIRCUIT IN MILES
NON-LOADED #19 B. & S. G. CABLE
MEDIUM LOADED #19 B. & S. G. CABLE WITHOUT TERMINAL TRANSFORMERS
MEDIUM LOADED #19 B. & S. G. CABLE WITH TERMINAL TRANSFORMERS

FIG. 4.—Efficiency of No. 19 B. & S. gauge cable unloaded and medium loaded, with substation apparatus located directly at the ends of the circuits

high frequency is a good indication of the skillful design and careful manufacture of these coils.

The method of placing loading coils in cable circuits is illustrated by Fig. 3, which shows the photograph of a manhole containing loading coil cases. The cases which you see in this photograph each contain 49 loading coils. These are arranged in the case on seven spindles, there being one spindle in the middle of the case and six spindles arranged around it. The case is filled with insulating compound and special precautions are taken between the flanges to exclude water. Extending from the case to the main cable is a stub cable containing the wires leading into and out of the loading coils. This is spliced into the main cable so as to loop a loading coil winding into each side of each circuit which it is desired to load. In some cases where

Digitized by Google

it is desired to load aerial cables, cases similar to those shown in Fig. 3 are buried at the base of the pole and the stub containing the wires run up the pole to connect with the aerial cable.

The results obtained by applying medium loading to No. 19 B. & S. gauge underground cable, having a capacity of about 0.070 microfarads per mile, are shown in Fig. 4. In this figure is also shown the transmission efficiency of the unloaded cable. All of these transmission efficiencies are measured in terms of what we call standard No. 19 gauge cable. This standard 19 gauge cable is cable having a resistance of 88 ohms per loop mile and a mutual capacity of 0.054 microfarads per mile. Cables as now manufactured have in general higher capacities than this, but when the earlier transmission tests were made cable having a mutual capacity of 0.054 was in common use and was therefore adopted as the standard and it has been convenient to retain it as such. Wherever in this paper, unless otherwise stated, the efficiency of a circuit is spoken of as being equivalent to so many miles of standard cable or of so many miles of cable, the cable referred to as the unit of measurement is 19 gauge standard cable as defined above. It is for this reason that the efficiency of the unloaded cable in Fig. 4 is not quite equal to that of the standard cable used as the unit of measurement.

The efficiencies of the loaded circuits, shown in Fig. 4, are those obtained with substation instruments located directly at the ends of the loaded circuits. One curve is given showing the results obtained by the use of terminal transformers and the other without the use of such devices. These curves bring out clearly a peculiarity of loaded circuits which should be considered at this point. The loading of a circuit, either underground or aerial, brings in at the ends of the loaded circuit whether the circuit is connected directly to substation instruments or to unloaded circuits an effect which we have called reflection losses. That is to say, at the ends of the loaded circuit there are certain losses which take place which are substantially independent of the length of the loaded circuit involved. These losses as between loaded and unloaded circuits are dependent upon the relative electrical characteristics of the loaded and unloaded circuits. In the case of substation instruments, connected directly to the ends of a loaded circuit, the terminal losses are dependent upon the relative electrical characteristics of the substation instrument and of the loaded line. Terminal or reflec-

Digitized by Google

tion losses, of course, also exist between unloaded lines of different characteristics, for instance, as between unloaded underground cable and unloaded aerial lines. They would also be found between substation instruments and unloaded lines of various kinds. In all these cases, however, they are small in magnitude and it is only in the case of loaded lines that they assume such proportions that they must be given consideration in connection with general engineering.

I have been speaking of the terminal losses observed in connection with loading as though they pertained particularly to the loaded line. It has been convenient to so speak of them but, of course, they actually pertain to the combination of loaded lines with unloaded lines or standard substation equipment, and properly are no more associated with one than with the other but rather result from a combination of the two. As, however, the substation instrument and the unloaded lines were in service for a considerable time before the use of loaded lines, it has been convenient to associate these reflection losses with the loaded lines and consider the electrical efficiencies of the unloaded lines and the substation instruments to remain unchanged.

Various devices have been successfully employed to reduce terminal losses, although no plan has been worked out which would completely eliminate them. The plan used most successfully to-day for eliminating terminal losses is a device known as a terminal transformer. This is a transformer or repeating coil which differs from the standard telephone repeating coil in that there are more turns on one winding than on the other. It is used in the same way as an ordinary transformer in electric light practice, the high potential side being connected with the loaded line and the low potential side with the unloaded line. For ordinary conditions of loading the ratio of the two windings is usually either 1 to 1.4 or 1 to 2. The effect of the terminal transformer in reducing terminal losses is well shown in Fig. 4. The terminal loss for the two ends of a medium loaded line without terminal transformers is about 5.75 miles of standard cable. With terminal transformers this is reduced to 2.5 miles. These figures are for cases where the telephone substation apparatus is located directly at the ends of the loaded line. Where, between the loaded line and the substation apparatus, there is a length of unloaded line it is found that terminal losses are not so great as if the terminal apparatus were directly at the ends of the loaded line. The extent to which the varying amounts of un

Digitized by Google

loaded line reduce terminal losses are shown by the following figures:

Amount of 19 gauge unloaded cable at each end of loaded circuit	Amount of terminal losses at both ends of a loaded circuit—medium loaded	
	Without terminal transformers	With terminal transformers
None	5.75	2.5
1 mile	4.0	2.0
2 miles	3.0	1.50
3 miles	2.2	1.15
4 miles	1.6	1.0
5 miles	1.25	0.9

While terminal losses are substantially independent of the length of the loaded line, they are affected by the character of the loading of the line. The heavier the loading the greater the reflection losses. While with medium loading the reflection losses, as shown by the above table, with no unloaded cable at the ends of the circuit are 5.75 miles without terminal transformers and 2.5 miles with terminal transformers, the corresponding figures for heavy loading are 7.8 miles and 3.5 miles. These figures are, of course, reduced as in the case of medium loading, by having unloaded cable at the ends of the loaded circuit.

If it were not for these terminal losses it would be practicable, theoretically at any rate, to indefinitely increase the efficiency of a 19 gauge circuit by adding more and more inductance to it. Even without terminal losses, however, this could not practically be done, because more and more loading coils would have to be added as more inductance was added, and these would in turn bring in larger and larger losses until finally the further gains from adding inductance would be offset or more than offset by coil losses. The increasing effect of leakage as the weight of loading is increased also has a limiting effect. Aside from these effects, terminal losses, which increase as the amount of inductance added to the circuit is increased, places a limitation beyond which it is not advantageous to increase the amount of loading on the circuits. This is illustrated by Fig. 5, which gives the efficiency of medium and heavily loaded 19 gauge conductors and on which, for the purposes of comparison, the efficiencies of various gauges of unloaded circuits are also given. It will be seen from this that by taking into account the reflection losses

Digitized by Google

which are here given at about an average for various conditions, the medium loaded circuit is more efficient than the heavily loaded circuit in lengths up to four miles. Beyond that point the heavily loaded circuit is more efficient, although even at 12 miles the difference is not largely in favor of the heavy loading.

It is interesting to consider from this diagram what results have been obtained from loading 19 gauge conductors. For a length of circuit equal to 4.5 miles the 19 gauge conductor with medium loading is as good as a 16 gauge conductor unloaded; that is to say, loading has made the circuit containing half the copper as good as the larger circuit without loading. For a length of 11 miles a loaded 19 is as good as unloaded 13 weighing four times as much as the 19 gauge conductor.

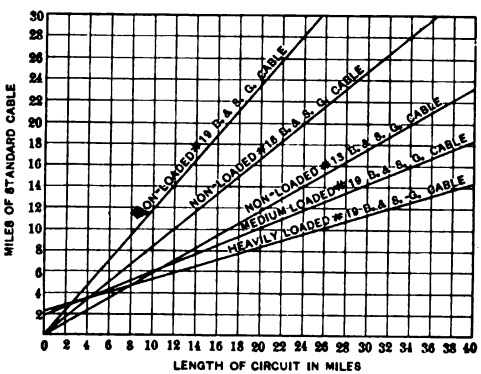

MILES OF STANDARD CABLE
LENGTH OF CIRCUIT IN MILES
NON-LOADED #19 B. & S. G. CABLE
NON-LOADED #16 B. & S. G. CABLE
NON-LOADED #13 B. & S. G. CABLE
MEDIUM-LOADED #19 B. & S. G. CABLE
HEAVILY-LOADED #19 B. & S. G. CABLE

FIG. 5.—Efficiency of No. 19 B. & S. gauge cable loaded, (medium and heavy), with terminal transformers and one mile unloaded loop at each end; also efficiency of unloaded cables of various gauges

For underground circuits, requiring a greater transmission efficiency than can be obtained by the use of heavily loaded 19 gauge cable circuits, it has been found best, all things considered, to employ a larger gauge of wire rather than to load more heavily. Many cables containing 16, 14 and 13 B. & S. gauge conductors have been laid and loaded.

The most interesting existing cable containing large gauge conductors is the New York-Philadelphia cable which was laid several years ago between these two points in order to provide additional circuits and to insure the service against storm damage. Most of the circuits in this cable are of 14 B. & S. gauge and they are heavily loaded. That is, there is 0.2 henry per mile added to the cable circuits by means of loading coils. The results obtained

Digitized by Google

on these circuits are given in Fig. 6 assuming average terminal conditions. The results obtained by this loading are most satisfactory. The distance between New York and Philadelphia, following the route of the cable, is 90 miles and this distance is indicated on the diagram. It will be seen that for this distance the circuits have an efficiency of 13 miles of standard cable. If unloaded, these circuits would have an efficiency of about 60 miles of standard cable. Over such circuits no commercial service could be given between New York and Philadelphia. Without loading, even 10 gauge conductors would have given unsatisfactory results, so that by means of loading we have been able to obtain results between New York and Philadelphia over

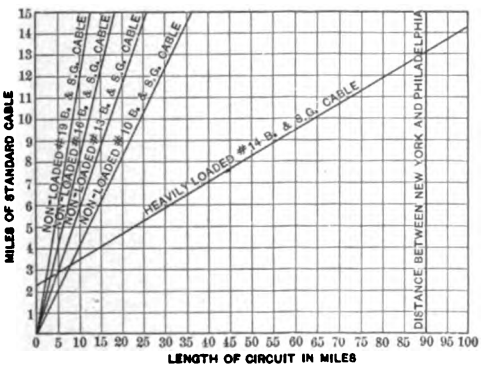

MILES OF STANDARD CABLE
LENGTH OF CIRCUIT IN MILES
NON-LOADED #19 Gr. B. & S.G. CABLE
NON-LOADED #16½ & S.G. CABLE
NON-LOADED #13 Gr. & S.G. CABLE
NON-LOADED #10 Gr. B. & S.G. CABLE
HEAVILY LOADED #14 Gr. & S.G. CABLE
DISTANCE BETWEEN NEW YORK AND PHILADELPHIA

FIG. 6.—Efficiency of No. 14 B. & S. gauge cable with heavy loading, (New York-Philadelphia cable); terminal losses with terminal transformers and one mile loop; also unloaded cables of various gauges

14 gauge conductors that could not have been obtained with conductors of much greater weight without loading.

While this New York-Philadelphia cable represents the longest loaded underground cable to-day in use anywhere in the world, a project has been approved and is now under way which will far surpass it. This project is for an underground cable extending between New York and Washington in one direction and New York and Boston in the other. The largest conductors in this cable will be No. 10 B. & S. gauge and by means of loading we confidently expect that we will be able to obtain thoroughly satisfactory results between New York and either Boston or Washington, and that it will even be possible to obtain service through this cable between Washington and Boston should storm

Digitized by Google

damage to the open wire lines render this necessary. The loading of this cable will be of particular interest as it will represent the first large application of the phantoming of loaded cable circuits and the loading of phantom cable circuits. In order to accomplish these results it is necessary to adopt special arrangements of the windings of the loading coils. The windings on the loading coil used for loading the side circuits are arranged as

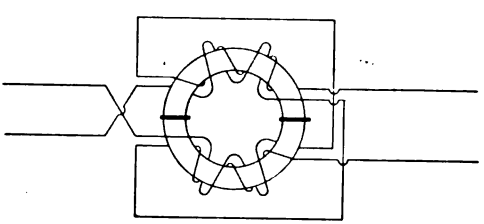


FIG. 7.—Diagram of winding of loading coil for circuits forming the sides of phantom

shown in Fig. 7. With this arrangement of winding, the effect of the telephone current in the side circuit, which current flows in opposite directions in the two sides of the circuit, is to magnetize the core of the loading coil in the same direction throughout and to produce no consequent poles. The loading coil thus acts, in as far as the side circuit is concerned, exactly like the loading coil with the simple winding shown in Figs. 1 and 2. In building

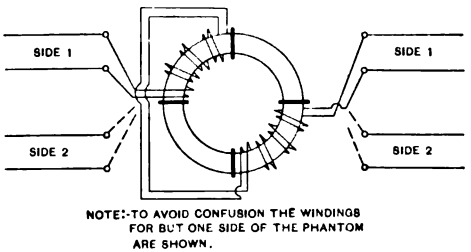


FIG. 8.—Diagram of winding of loading coil for use on phantom circuits

up a phantom circuit this side circuit, however, becomes one side of the phantom, and the telephone current in the phantom circuit traverses the two wires of the side circuit in parallel. Such a current flowing through the windings of such loading coils as are shown in Figs. 1 and 2 would magnetize the two sides of the core in opposite directions and produce consequent poles at the two sides of the core. This would not only bring in

Digitized by Google

serious losses, but also crosstalk which would be very difficult to deal with. The current in the phantom circuit flowing through a coil with windings on it as shown in Fig. 7 does not magnetize the loading coil at all, as each winding is neutralized by a corresponding winding on the other side of the line. Such coils may be used to effectively load the side circuits of a phantom combination and in as far as the phantom itself is concerned they act only as resistance which is very small in amount. This, however, does not load the phantom circuit, which of course is a desirable result to attain. To load the phantom circuit a coil with windings as shown in Fig. 8 is employed. It will be seen by tracing out the winding of this coil that to the current flowing in the phantom circuit it acts like an ordinary loading coil, that is, all windings magnetize the core in the same direction. To currents flowing in either of the side circuits, however, it acts only as dead resistance. The arrangements described above in connection with the application of loading coils to phantom circuits and to the side circuits of phantom circuits have been successfully applied to open wire lines as well as to underground cables.

Loading Open Wire Lines

Gratifying as have been the results obtained from the use of loading on underground cables, its application to open wire circuits has also resulted in most noteworthy improvements in their efficiency. The general plan of loading open wire circuits is similar to that used on underground cable wires. On account of the differences in the electrical characteristics of open wire circuits, as compared with cable circuits, however, the design and spacing of the loading coils is materially different from the coils and the spacings used on underground cables. In general, only heavy loading is used on open wire lines on account of the greater length of these lines. The coils themselves are substantially larger than those employed on cable circuits for two reasons—in the first place the coil is subject to damage by lightning. In order to minimize this difficulty the coils must be built to have high breakdown strengths against lightning discharges. All aerial coils are built so that they will stand a breakdown test of 8,000 volts. This, of course, considerably increases the size of the coil. The coil is further increased in size by the fact that, as an aerial circuit is initially a good deal more efficient than an underground circuit, it is necessary that the coils used in loading it should have smaller losses than are

Digitized by Google

permissible in underground cable loading coils. The outside diameter of the aerial loading coil is about 10 inches and the resistance of the two windings of the coil to direct current is 2.5 ohms while to alternating currents of a frequency of 800 periods a second it is 6.5 ohms. In addition to building the coil so that it has a breakdown strength of 8,000 volts, each coil is protected by a pair of lightning arresters adjusted to operate at 3,500 volts. These precautions have proved sufficient to reduce trouble from lightning on aerial loading coils to a negligible amount.

Low insulation which is sometimes encountered on open wire lines, particularly in periods of bad weather, proved at the start

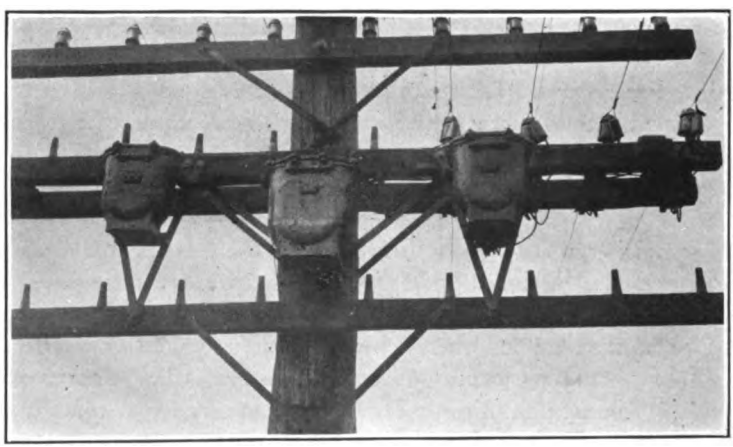


FIG. 9.—Loading coils placed on an open wire line

a serious difficulty in connection with the loading of open wire lines. This, however, has been overcome by removing the worst causes of low insulation and in some cases by the use of improved insulators, and at the present time low insulation is not proving a serious factor in connection with the application of loading to overhead lines. In wet weather the transmission efficiency of overhead lines is not quite as good as in dry weather, but it may be stated that it is very seldom that the loaded circuits fall in efficiency sufficiently to seriously affect the transmission, except in cases where the lines are in actual trouble from branches of trees falling into the line or other similar causes.

In connection with the loading of open wire lines the problem

Digitized by Google

of arranging them so that they will be free from substantial crosstalk has required attention. Due to the fact that much of the crosstalk disturbance in telephony are from electrostatic induction it is to be expected and it is found in practice that the loading of a circuit increases its tendency to crosstalk. In the early applications of loading to open wire lines some trouble was experienced from crosstalk and special transposition systems were devised to overcome these difficulties and it was further found necessary to locate the loading coils with special reference to the transpositions. On underground cables it has been found that loading also increases the crosstalk somewhat, and in these we arrange to reduce the capacity unbalances in order to reduce crosstalk to a sufficiently low point.

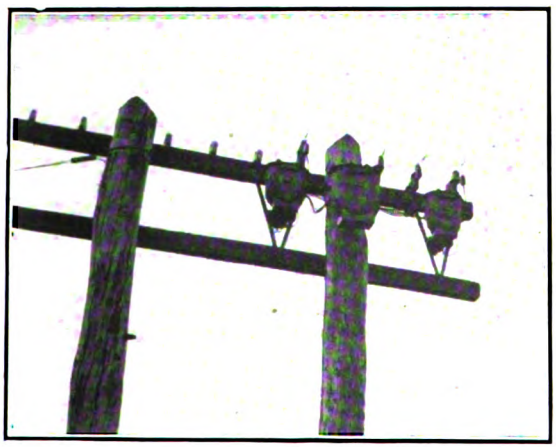


FIG. 10.—Loading coils placed on an open wire line on "*H*" Fixtures

The loading coils for use on open wire circuits are placed in individual cast iron cases and these are placed on the poles or crossarms as in Figs. 9 and 10 which show illustrations of two common arrangements. The line is carried to the loading coil by means of bridle wire. The lightning arrester is placed in a separate case and bridle wire is also extended to it.

The results obtained by the use of loading coils on the No. 8 B. W. and No. 12 N. B. S. gauge wires, which are the standard sizes used in the long distance plant of the Bell system, are shown in Fig. 11, in which for the purposes of comparison the efficiencies of the unloaded circuits are also given. This diagram

Digitized by Google

shows terminal losses with the conditions which may be considered as average. The general reflection loss problem with overhead lines is the same as with underground cables, and having been discussed in detail in connection with such circuits it need not be repeated here. As will be seen from Fig. 11 the results obtained from loading open wire lines have been to more than double their transmission efficiency when used in considerable lengths.

One of the very valuable results which has followed from the loading of open wire lines has been that it has made a very substantial extension to the distance over which long distance service can be given. Up to the time that loading was successfully applied to No. 8 B. W. G. wires, about 1,000 miles repre-

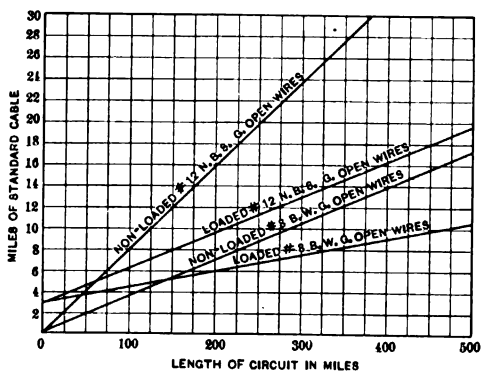

MILES OF STANDARD CABLE
LENGTH OF CIRCUIT IN MILES
NON-LOADED #12 N. B. S. G. OPEN WIRES
LOADED #12 N. B. S. G. OPEN WIRES
NON-LOADED #8 B. W. G. OPEN WIRES
LOADED #8 B. W. G. OPEN WIRES

FIG. 11.—Efficiency of No. 8 B. W. G. and No. 12 N. B. S. G. open wire lines loaded and unloaded with average terminal conditions

sented the greatest distances over which commercial service was maintained. By the loading of No. 8 circuits this has just been extended to 2,000 miles, so that to-day it is practicable to obtain a successful telephone conversation from New York to Denver. The actual distance between these two points by the route which the line follows is 2,010 miles.

A very important use has been made of loaded cables in bringing loaded open wire lines into large cities. Loaded cables have also been used to bring unloaded open wire lines into thickly settled communities, but in this case the gains have not been so great because it is not practicable to place terminal transformers for reducing the reflection losses between the outer end of the underground cable circuits and the aerial lines, and hence reflection losses are experienced.

Digitized by Google

This practical impossibility of placing reflection reducing devices between open wire and cable has also made it impossible to obtain the full benefits from loading in those cases where short stretches of cable are placed in the middle of toll lines—*e.g.*, in communities where the appearance of the open wires is objected to and requests are made to place them underground. If the open wires are loaded the trouble is not so great as a comparatively heavy loading can be used without excessive reflection losses. For non-loaded open wires, the loading of the cable if attempted at all must be very light if the reflection losses are not to offset any gain from the reduced attenuation.

For these reasons and also because cable circuits loaded or non-loaded are inherently less efficient than open wire circuits it is important that every effort be made to keep toll lines as free as possible from cable.

Loading of Submarine Cables

The problem of loading submarine cables is a mechanical one rather than one concerning the principles of loading. In this country a 16 B. & S. G. dry core paper submarine cable about 5 miles long and containing loading coils spaced about 2 miles apart has been successfully laid across the Chesapeake Bay and is now in operation. There has also been talk of laying a dry core loaded submarine cable across Puget Sound for a distance of 16 miles. The situation in the United States, however, is not such that large numbers of loaded submarine cables of any great length are required. Abroad, however, particularly between England and the continent and between England and Ireland submarine cables of considerable length are needed for telephone purposes and in these situations loaded gutta-percha submarine cables have been employed with successful results.

Extent of Application of Loading

It is evident that a device making such great improvements in the transmission efficiency of telephone circuits as does loading would have a large place in the plant of any company providing a comprehensive system of telephone service over a large area, a condition necessarily requiring long cables and long open wire lines. Although the loading art was born in 1900, and its successful commercial application on an extensive scale to our plant dates only from about 1903, there are already in the United States over 85,000 miles of loaded open wire circuits and over

Digitized by Google

170,000 miles of loaded underground cable circuits. To load these circuits there have been employed about 125,000 loading coils. The day-by-day experience with this enormous loaded line plant has fully demonstrated that we are in practice obtaining the successful results which the engineering data that I have set forth would lead us to expect.

The facts which have been herewith developed have, I think, been more than sufficient to justify the statement at the beginning of this paper, that the year 1900, in which the loading patents were issued to Professor Pupin, marked the beginning of an important era in telephone work. I do not know of any problem in electrical science and electrical engineering which has required greater skill, technical ability and diligence on the part of those engaged in its solution—inventors, engineers, manufacturers and construction people—than has the working out and the application of loading, and it is a pleasure to be able to present to you a statement of the results which they have accomplished.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26–30, 1911.

Copyright 1911. By A. I. E. E.

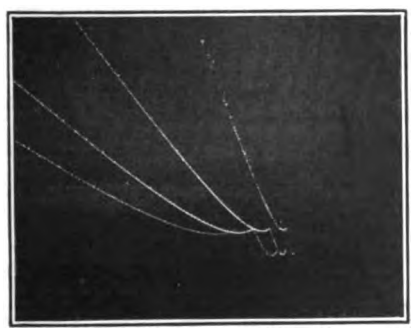
(*Subject to final revision for the Transactions.*)

THE LAW OF CORONA AND THE DIELECTRIC STRENGTH OF AIR

BY F. W. PEEK, JR.

I. SUMMARY

For several years an extensive investigation on the *dielectric strength of air*, and more particularly, on the law of corona, has been carried on by the Consulting Department of the General Electric Company, under the general supervision of Dr. C. P. Steinmetz. The facilities were practically unlimited in regard



Corona, standard Line A, No. 3/0 Cable
310 cm. spacing, 230,000 volts

to power, apparatus, instruments and their standardization, and available engineering skill. Thanks for their active assistance in this investigation are due to Dr. E. J. Berg, Messrs. C. M. Davis, J. L. R. Hayden, A. B. Hendricks, W. K. Page, L. T. Robinson, L. A. Schloss, W. I. Schlicter, C. W. Stone and J. B. Taylor.

The investigation gives the following results:

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

1. In alternating-current transmission lines at very high voltages a loss occurs by dissipation of power into the air. This is accompanied by luminosity of the air surrounding the line conductor—the so-called corona.

Loss begins at some critical voltage, which depends on the size and spacing of line conductors, etc., and increases very rapidly above this voltage. Fig. 1 shows a typical curve of corona loss.

An extended investigation on an experimental transmission line has shown that the corona loss in *fair weather* can be expressed by the equation

$$p = a f (e - e_0)^2 \qquad (1)$$

where p = loss, in kilowatts per kilometer length of single line conductor.

e = effective value of the voltage between the line conductors and neutral in kilovolts.*

f = frequency,

and a is given by the equation

$$a = \frac{k}{\delta} \sqrt{\frac{r}{s}} \qquad (2)$$

where r = the radius of conductor in cm.

s = the distance between conductor and return conductor in cm.

δ = the density of the air, referred to the density at 25 deg. cent. and 76 cm. barometer as unity.

k = a constant.

e_0 = the effective *disruptive critical* voltage to neutral, and is given by the equation

$$e_0 = m_0 g_0 \delta r \log_e \frac{s}{r} \text{ kv. to neutral} \qquad (3)$$

where g_0 is the disruptive gradient of air in kilovolts per cm. at 25 deg. cent. and 76 cm. barometer, and is constant for all sizes of wires, frequencies, etc. If the effective value of g_0 is taken, e_0 is given in effective kilovolts.

*Hence, in single-phase circuits, e is one-half the voltage between conductors. In three-phase circuits e is $\frac{1}{\sqrt{3}}$ times the voltage between conductors.

Digitized by Google

From our investigations it follows that

$$g_0 = 29.8 \text{ kv. per cm. (maximum)}$$

$$g_0 = 21.1 \text{ kv. per cm. (effective)}$$

m_0 is a constant depending on the surface condition of the conductors, and

$m_0 = 1$ for perfectly smooth polished wires.

$m_0 = 0.98$ to 0.93 for roughened or weathered wires, and decreases to

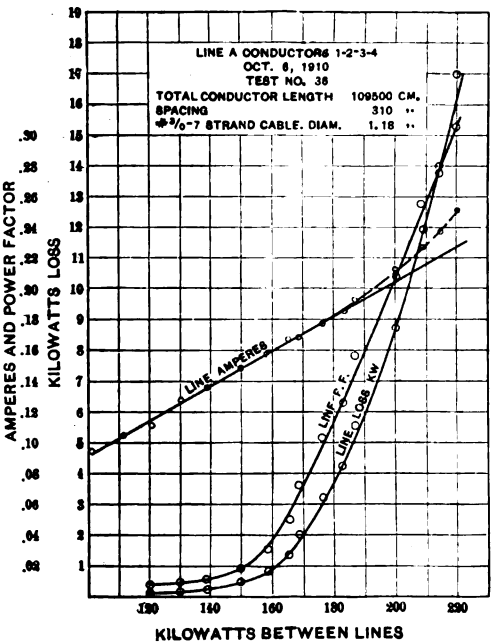


FIG. 1.—Corona loss characteristic curves

$m_0 = 0.87$ to 0.83 for 7 strand cables (where the radius is taken as the outer radius of the cable).

2. Luminosity of the air surrounding the line conductors does not begin at the *disruptive critical voltage* e_0, but at a higher voltage e_v, the *visual critical voltage*.

The *visual critical voltage* e_v, is much higher for small wires than the *disruptive critical voltage*, e_0; it is also higher for large wire, lent to a lesser extent.

While theoretically no loss of power should occur below the *visual voltage*, e_v, some loss does occur, due to irregularities of the

Digitized by Google

wire surface, dirt, etc. Thus, for the line voltage, e, near the critical voltage, e_0, the corona loss is greater than given by equation (**1**) for large wires, and smaller for small wires, as shown by curves, Figs. 2 and 3.

The curves as drawn are calculated from equation (**1**); the points shown by circles are the measured experimental values.

At the low values of corona loss, two effects occur, which cause this deviation of the loss from the quadratic law, equation (**1**), and which affect the loss in opposite directions:

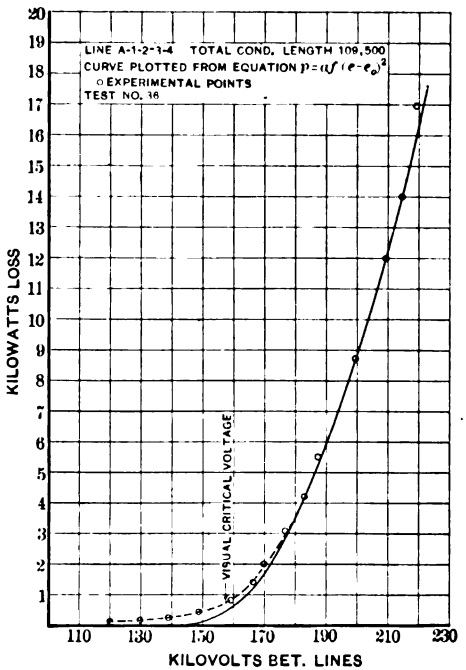


FIG. 2.—Corona loss characteristic curves

a. The loss of power does not begin at the voltage e_0, at which the disruptive gradient is reached at the conductor surface, but only after the disruptive strength of air has been exceeded over a finite and appreciable distance from the conductor, that is, at a higher voltage e_v. As the convergency of the lines of dielectric force is great at the surface of small conductors, a considerable increase of the voltage is required to extend the disruptive gradient to some distance from the conductor, and e_v is considerably higher than e_0. Therefore the decrease of loss

Digitized by Google

below that given by equation (1) is appreciable with small conductors within the range between e_0 and e_v, as seen in Fig. 3. With large conductors however, the lesser convergency of the lines of dielectric force at the conductor surface requires a lesser voltage increase beyond e_0, to extend the disruptive gradient for some distance from the conductor, and e_0 and e_v are therefore closer together, and this decrease of the loss below the theoretical value given by equation (1) is not appreciable.

b. As the conductor surface can never be perfect, some loss

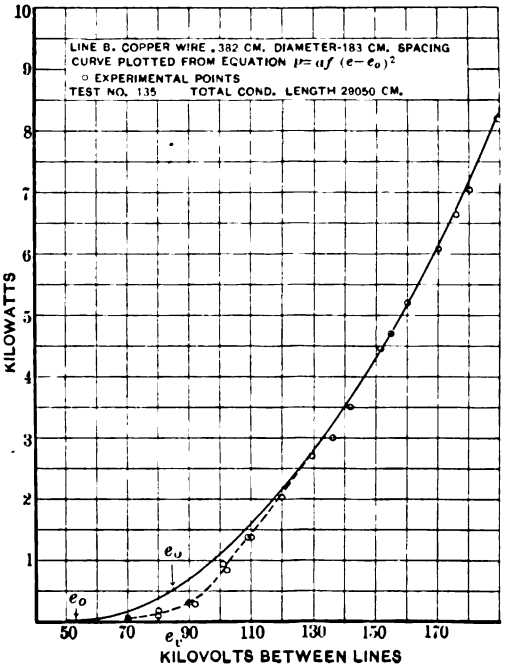


FIG. 3.—Corona loss

of power occurs at and below the disruptive critical voltage at isolated points of the conductor, where irregularities of the surface, scratches, spots of mud or dirt, etc., give a higher potential gradient than that corresponding to the curvature of the conductor surface. With small conductors, this loss is rarely appreciable, since the curvature of the conductor surface is of the same magnitude as that of its irregularities. It becomes appreciable however for larger conductors, as seen in Fig. 2. This excess of the loss beyond that given by the quadratic law,

Digitized by Google

equation (1), essentially depends on the conductor surface, and is larger, the rougher or dirtier the surface is. It is a maximum at the disruptive critical voltage e_0, and decreases above and below e_0. It is with fair accuracy represented by the probability curve:

$$p_1 = q\,\epsilon^{-h(e_0-e)^2} \qquad (4)$$

where g is a coefficient depending on the number of spots, and h is a coefficient depending on the size of spots.

Snow, sleet and rain losses seem to be of the same nature, but frequently of far greater magnitude.

The visual critical voltage, e_v, is derived from the disruptive gradient, g_0, by the equation

$$e_v = m_v\, g_0\, \delta\, r \left(1 + \frac{0.301}{\sqrt{r}}\right) \log_e \frac{s}{r} \text{ kv. to neutral} \qquad (5)^*$$

where $m_v = m_0 = 1$ to 0.93 for wires.

$m_v = \begin{cases} 0.72 \text{ local corona all along conductor;} \\ 0.82 \text{ decided corona all along conductor,} \end{cases}$ for seven-strand cables

If g_0 (maximum) is used, e_v is obtained in maximum kilovolts.

From (1), (2) and (3) then follows the complete expression of the corona loss in fair weather, at voltages above the visual critical voltage, e_v,

$$p = \frac{k}{\delta} f \sqrt{\frac{r}{s}} \left\{ e - g_0\, m_0\, r\, \delta \log_e \frac{s}{r} \right\}^2 10^{-5} \text{ kw. per km. of single conductor} \qquad (6)$$

where e = effective kilovolts to neutral.

$k = 344$.

$g_0 = 21.1$ kv. per cm. (effective).

δ = air density factor $= \dfrac{3.92\,b}{273+t}$.

$\delta = 1$ at 25 deg. cent. and 76 cm. barometric pressure.

b = barometric pressure cm.

t = temperature deg. cent.

r = radius of conductor, cm.

s = distance between centers of conductors, cm.

f = frequency, cycles per second.

*NOTE:—The visual critical point for wires is very sharp and definite, while for cables it is not so well defined.

Digitized by Google

m_0 = irregularity factor.

$m_0 = 1$ for polished wires.

$= 0.98 - 0.93$ for roughened or weathered wires.

$= 0.87 - 0.83$ for seven-strand cable.

The corona loss is

a. Proportional to the frequency f.*

b. Proportional to the square of the excess voltage above the disruptive critical voltage, e_0.

c. Proportional to the square root of the conductor radius r, and inverse proportional to the square root of the conductor distance.

The disruptive critical voltage, e_0, is that voltage at which the disruptive voltage gradient of the air is reached at the conductor surface. Hence, it is:

a. Proportional to the conductor radius, r, and the $\log_e \frac{s}{r}$.

b. Proportional to the air density.

c. Depending somewhat on the condition of the conductor surface as represented by m.

3. The effects of various atmospheric conditions and storms on the critical voltage and loss will now be considered.

Humidity or " vapor products " have no effect on either the critical voltage or the loss.

Smoke lowers the critical voltage and increases the loss.

Heavy wind has no effect on the loss or critical voltage at ordinary commercial frequencies.

The weather conditions that really count practically and which must be seriously considered in the design of transmission lines are as follows:

Fog lowers the critical voltage and increases the loss.

Sleet on the wires, or falling sleet, lowers the critical voltage and increases the loss. High voltages do not entirely eliminate sleet formation.

Rain storms lower the critical voltage and increase the loss.

Snow storms lower the critical voltage and increase the loss. The effect of snow is greater than that of any other weather condition.

Fig. 4 shows the loss during fair weather, and a corresponding loss during a snow storm.

*It is probable that at extremely low frequencies, the loss decreases less than proportional to the frequency, and approaches a small finite limiting value at continuous impressed voltage.

Digitized by Google

The excess loss, during sleet, rain or snow storms, over the fair weather loss, seems with increasing voltage to approach a maximum and then to decrease again (the latter at values very far above the disruptive critical voltage), and the curves of excess loss seem to have the general shape of probability curves, as is to be expected theoretically.

4. The following problem is given in order to show the method of applying the results to an actual transmission line.

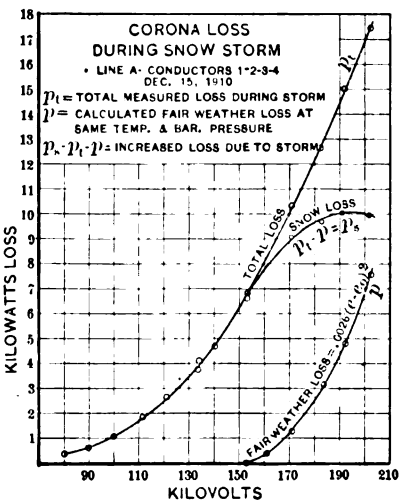

CORONA LOSS
DURING SNOW STORM
• LINE A- CONDUCTORS 1-2-3-4
DEC. 15, 1910
P_t = TOTAL MEASURED LOSS DURING STORM
P = CALCULATED FAIR WEATHER LOSS AT SAME TEMP. & BAR. PRESSURE
$P_s = P_t - P$ = INCREASED LOSS DUE TO STORM
KILOWATTS LOSS
KILOVOLTS
TOTAL LOSS
SNOW LOSS
$P_t - P = P_s$
FAIR WEATHER LOSS = $.0076(E-12.9)^3$
P

FIG. 4

EXAMPLE

Given a line—three-phase—60 cycles.

Length	= 100 miles.
Spacing	= 10 feet.
Conductor	= No. 0 cable, diameter = 0.375 in.
Maximum temperature	= 100 deg. fahr.
Elevation	= 1000 ft.

Required

(*a*) Disruptive critical voltage.

(*b*) Visual critical voltage.

(*c*) Loss (fair weather).

(*d*) Loss (during snow storm) assuming $e_0 = 80$ per cent of fair weather e_0.

Digitized by Google

Solution

Reducing to metric units

Length	= 161 km.
Spacing	= 305 cm.
Conductor radius	= 0.478 cm.
Maximum temperature	= 38 deg. cent

Elevation being 317 m.

Barometer corresponding = 73.4 cm.

(*a*) Disruptive critical voltage.

From formula (**3**)

$$e_0 = m_0\, g_0\, \delta\, r \log_e \frac{s}{r}$$

$m_0 = 0.87$ value for seven-strand cables

$g_0 = 21.1$ kilovolts per cm. (effective).

$$\delta = \frac{3.92\, b}{273+t} = \frac{3.92 \times 73.4}{273+38} = 0.929$$

$r = 0.478$ cm.

$$\log_e \frac{s}{r} = 6.46$$

Evaluating

$e_0 = 52.7$ kilovolts to neutral

Therefore the disruptive critical voltage between conductors $= 52.7 \times \sqrt{3} = 91.3$.

b. Visual critical voltage.

From formula (**5**)

$$e_v = m_v\, g_0\, \delta\, r \left(1 + \frac{0.301}{\sqrt{r}}\right) \log_e \frac{s}{r}$$

Evaluating

$e_v = 71.1$ kv. for decided corona.

$e_v = 62.5$ kv. for local corona.

Therefore, visual critical voltage between wires

$= e_v \times \sqrt{3}$.

= 125 kv. for decided corona.

108 kv. for local corona.

c. Power loss (fair weather).

Digitized by Google

From formula (6).

$$p=\frac{k}{\delta}f\sqrt{\frac{r}{s}}\left\{e-g_0\,m_0\,r\,\delta\log_e\frac{s}{r}\right\}^2 10^{-5}\text{ kw. per km. of single conductor.}$$

e = effective kilovolts to neutral.
$k=344.$
$\delta=0.929.$
$f=60.$
$\sqrt{\frac{r}{s}}=0.0396.$
$g_0=21.1.$
$\log_e\frac{s}{r}=6.46.$

Evaluating and multiplying by three, since we have three conductors, we obtain

$$p=2.64\ (e-52.7)^2\ 10^{-2}\text{ kw. per km.}$$

Substituting values for line volts

Fair weather				Storm	
e between line	e to neutral	p	$p_{\text{total}}=p\times161$	p	$p_{\text{total}}=p\times161$
90	51.9	——	——	2.48	400
100	57.7	0.66	106	6.33	1020
110	63.4	3.02	485	11.90	1920
120	69.2	7.2	1160	19.20	3090
130	75.1	13.3	2140	28.70	4610
140	80.9	21.0	3380	39.50	6360
150	86.6	30.4	4890	52.10	8390

For approximate loss during storm consider $e_0=80$ per cent of its value in fair weather.

$$e_0=0.8\ \times52.7=42.2\text{ kv.}$$

Therefore:

$$p=2.64\ (e-42.2)^2\ 10^{-2}\text{ kw. per km.}$$

See curves, Fig. 5.

Digitized by Google

The formulae are here given in English units for the benefit of those who may desire them in this form.

1. e_0, the *effective disruptive critical voltage to neutral* is given by the equation:

$$e_0 = 2.302\, m_0\, g_0\, r\, \delta \log_{10} \frac{s}{r} \qquad (3a)$$

2. e_v, the *visual critical voltage* in effective kv. to neutral is obtained from the equation:

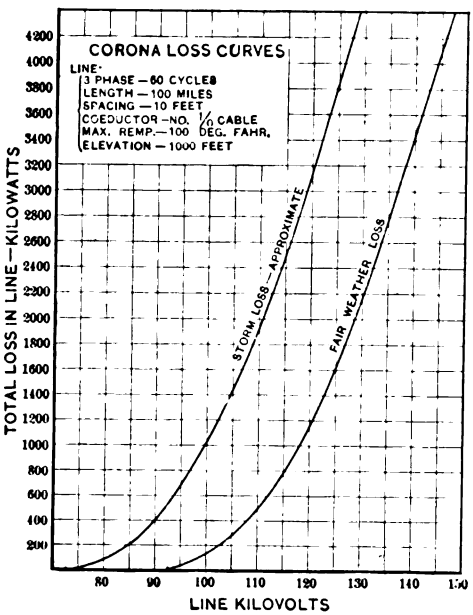


FIG. 5.

$$e_v = 2.302\, m_v\, g_0\, \delta\, r \left(1 + \frac{0.189}{\sqrt{r}}\right) \log_{10} \frac{s}{r} \qquad (5a)$$

3. p = the total power loss due to corona in fair weather, in kw. per mile of single conductor.

$$p = \frac{k'}{\delta} f \sqrt{\frac{r}{s}} \left\{ e - g_0\, m_0\, r\, \delta\, 2.302 \log_{10} \frac{s}{r} \right\}^2 10^{-5} \qquad (6a)$$

Digitized by Google

In the above equations:

e = effective kilovolts to neutral.

$k' = 552$.

$g_0 = 53.6$ kv. per in. (effective).

δ = air density factor $= \frac{17.91\ b}{459+t}$.

$\delta = 1$ at 77 deg. fahr. and 29.92 in. barometric pressure.

b = barometric pressure in inches.

t = temperature, deg. fahr.

r = radius of conductor inches.

s = distance between centers of conductors, inches.

f = frequency, cycles per second.

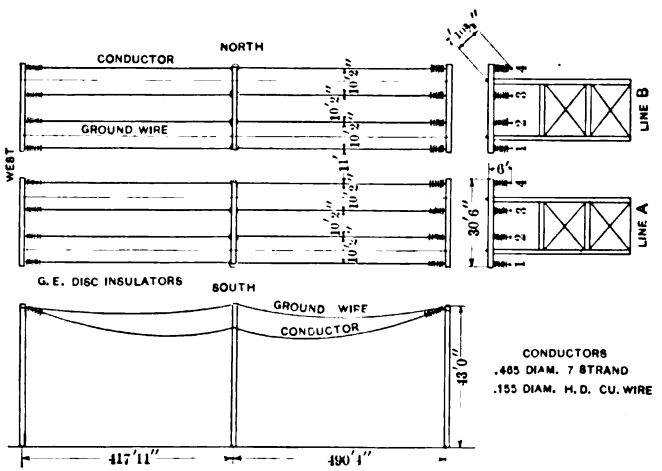


FIG. 6.—Corona loss—Original line arrangement used for preliminary tests.

m_0 = irregularity factor.

$m_0 = 1$ for polished wires.

$= 0.98$ to $.093$ for roughened or weathered wires.

$= 0.87$ to 0.83 for seven-strand cables.

$m_v = m_0$ for wires.

$m_v = \begin{cases} 0.72 \text{ local corona all along cable;} \\ 0.82 \text{ decided corona all along cable,} \end{cases}$ for seven-strand cables.

If g_0 maximum is used, e_v is obtained in maximum kilovolts.

II. LINES, APPARATUS AND METHOD OF TEST

The Lines. The conductors used in the following investigations were supported by metal towers arranged in two parallel

Digitized by Google

lines of two spans each. The length of each span was approximately 150 m. These tower lines will be designated by A and B respectively. The conductors were strung in a horizontal plane with seven disk suspension insulators at each point of support. For preliminary tests four No. 3/0 B. & S. (1.18 cm. diameter) seven-strand hard-drawn copper cables were put in place on each line. A seven-strand steel ground cable was also strung. (See Fig. 6). After a number of tests had been made the ground cables were removed from line A. The conductors on line A, however, were kept in place as a standard throughout all the investigations. The conductors and ground cables were removed from B, and the first span of this line was used to support various sizes of conductors at various spaces (see Fig. 7).

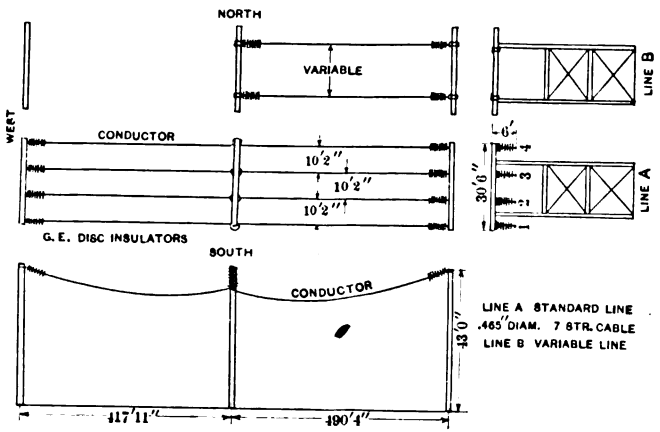


FIG. 7.—Corona loss—Final line arrangement

These lines were erected in a large field. The prevailing winds were from the west over open country, that is, free from smoke from the city and the factory on the east. Figs. 8 and 9 show a view of the towers, and Fig. 10 shows one link of the insulators used.

Test Apparatus. A railroad track was run directly under the line, and the testing apparatus was housed in three box cars. This proved a very convenient arrangement, as the cars could be quickly run back to the factory when changes or repairs were necessary.

Power was received in substation car No. 1 at 550 volts 40 cycles, and changed to direct current by a converter. This in

Digitized by Google

turn was used to supply a direct current motor, belted to a single-phase alternator. This last, was an old Thomson-Houston machine with a smooth core pan cake winding on the armature; it gave a very good wave, and was used in all tests. See oscillogram and analyzed wave, Fig. 11. It was rated at 35 kw., but this rating was quite conservative.

The high voltage transformer and the testing apparatus were placed in car No. 2. The portion of the car roof over the trans-

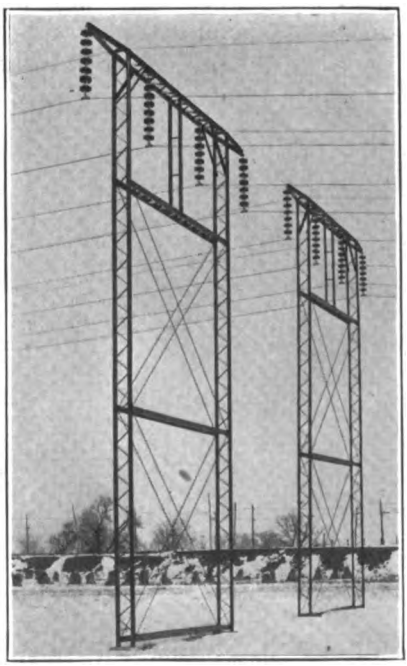


FIG. 8.—Intermediate transmission towers

former was made of heavy canvas. This was quickly rolled back, and the leads from the line were dropped directly to the transformer terminals. By means of a frame work and canvas cover the transformer could be protected from the weather, and investigations carried on during rain and snow storms. The power supply, speed and voltage, were all controlled from car No. 2. In fact all of the adjustments could be made from this car (see Fig. 12 and 13). The transformer was rated at 100 kw., 200,000 volts and 60 cycles. On the low side were four 500 volt

Digitized by Google

coils. These coils could be connected in multiple or series for change of ratio. The high-tension winding was opened at the neutral and taps were brought out for the ammeter, and current coil of the wattmeter. Three taps were also brought out here

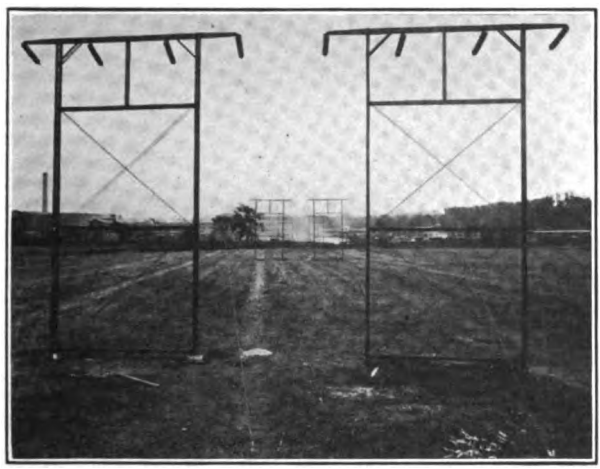


FIG. 9.—Experimental transmission line looking east

from the main winding for voltage measurement. See Fig. 13. The following tap ratios were thus obtained 100/200,000; 200/200,000 and 400/200,000.

The transformer was specially designed for this work by Mr.

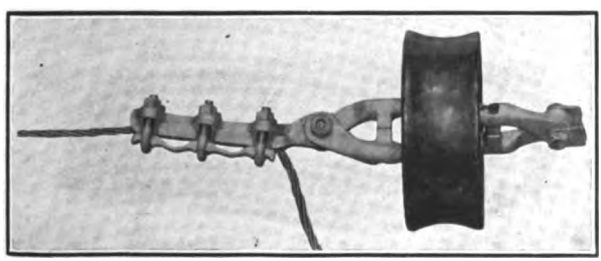


FIG. 10.—25,000-volt link strain insulator

A. B. Hendricks from experience gained in previous tests.*

Car No. 3 served as a dark room for making photographs and visual tests on short wires and cables. Fig. 13*a* shows the frame work used for supporting conductors in the visual tests.

*See A. I. E. E. TRANSACTIONS, February, 1911.

Digitized by Google

Methods of Test. Accurate power measurements of corona are very difficult to make, because of the nature of the load—low power factor and high voltage. It is not desirable to make the measurements on the low side because of the difficulty in separating the transformer iron and load losses, and these may be

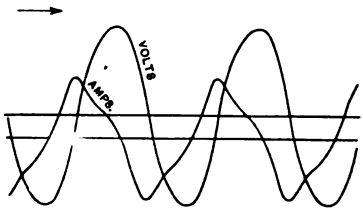


FIG. 11 (*a*).—Line *A* conductors 1, 2, 3, 4, 191 kv.

sometimes as large as the corona losses. In these tests the current coil of the wattmeter, and the ammeter, were put in the high tension winding of the transformer at the neutral point, and the neutral was grounded. See Fig. 13. The voltage coil of the wattmeter was connected to a few turns of the high tension

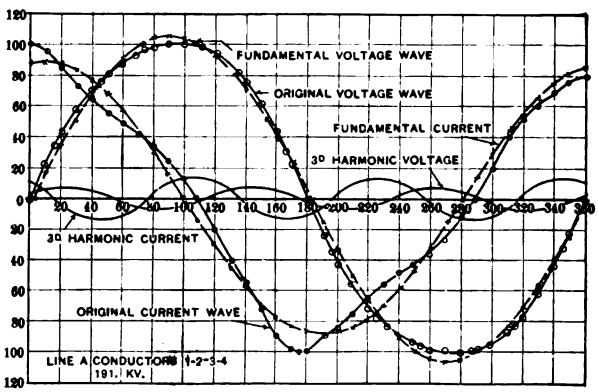


FIG. 11 (*b*).—Corona loss wave form analysis oscillogram *T* 40

winding at the neutral.* Voltage was also read in this manner. Another method of voltage measurement was also tried as a check, namely, by using the above turns as a separate winding. The results obtained by the two methods checked very well.

*See paper by A. B. Hendricks. A. I. E. E. TRANSACTIONS, February, 1911.

Digitized by Google

All the loss measurements were also duplicated on the low side as a check. Frequency was held at the test table by means of the motor field and a vibrating reed type of frequency meter.

Voltage was controlled in two ways—by the potentiometer method and by rheostats in the alternator field. By the po-

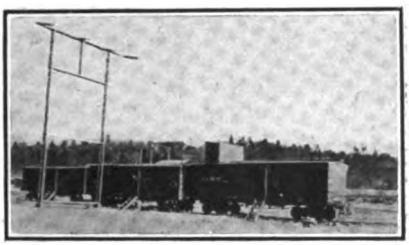


FIG. 12.—Cars Nos. 1, 2 and 3

tentiometer method is meant a series resistance on the low side of the transformer for voltage control and a multiple resistance across the transformer, taking about three times the exciting current, to prevent wave distortion. When the leading current was very high a reactance was arranged to shunt the generator

FIG. 12 (*a*).—Interior of car No. 2

and approximately unity power factor could be held. This prevented overloading the generator and reduced wave shape distortion. For a set of tests at a given frequency the ratio of the main transformer was kept the same. Where losses at several frequencies were to be compared the main transformer ratio also was changed to keep the flux on the generator as nearly

Digitized by Google

constant as possible—for instance at 45 cycles a ratio of 500/200,000 would be used, while at 90 cycles a ratio of 1000 to 200,000 would be used. Wattmeters with scales especially adapted to the tests were constructed. These were of the dynamometer type; they were each provided with a 75-volt and

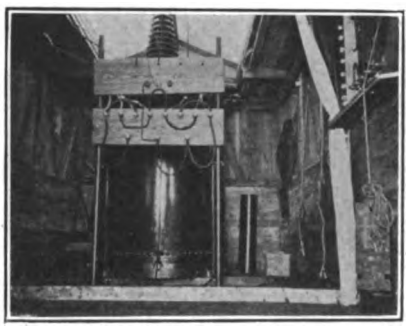


FIG. 12 (*b*).—Transformer end of car No. 2

150-volt tap. The voltmeter coil ratio on the transformer, and the wattmeter tap were always changed to give the best reading. Four wattmeters were used in these tests. The meters were all carefully calibrated in the laboratory at unity power factor and at 0.10 leading power factor, at both 25 and 60 cycles. See Fig. 14 for the meter scales.

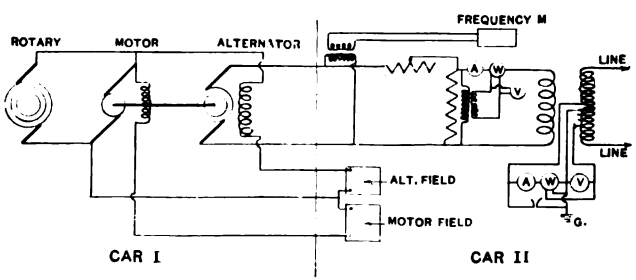


FIG. 13.—Arrangement and connections of apparatus used in corona tests

Humidity, temperature, and barometric pressures, as well as general weather observations were taken during each test.

III. THE QUADRATIC LAW

Table I is a typical data sheet for Line *A*.

Digitized by Google

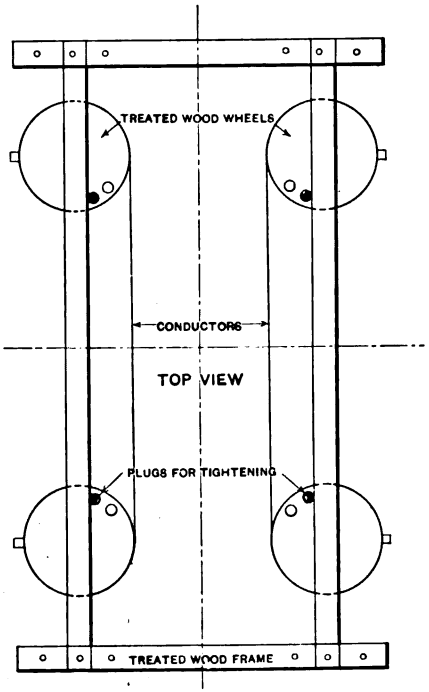


FIG. 13 (*a*)

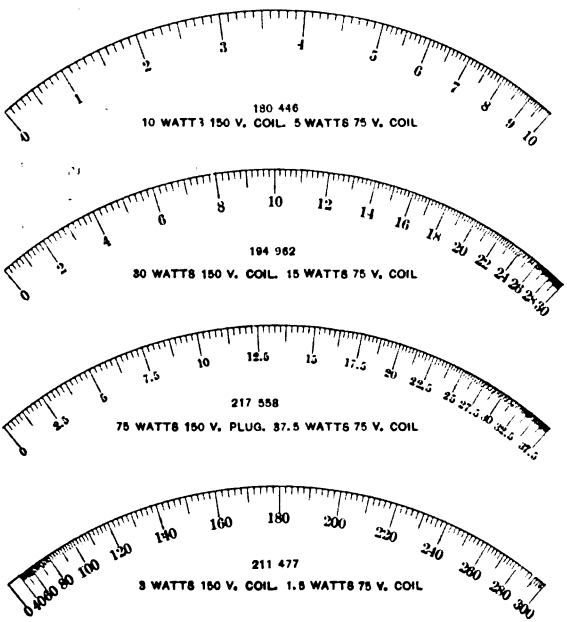

180 446
10 WATTS 150 V. COIL. 5 WATTS 75 V. COIL
194 962
30 WATTS 150 V. COIL. 15 WATTS 75 V. COIL
217 558
75 WATTS 150 V. PLUG. 37.5 WATTS 75 V. COIL
211 477
3 WATTS 150 V. COIL. 1.5 WATTS 75 V. COIL

FIG. 14.—Watt meter scales

Digitized by Google

TABLE I

EXPERIMENTAL LINE. 10-6-10 4 p.m.

Low side Total readings			High side Total readings		
Volts	Amperes	Kilowatts	Kilovolts	Amperes	Kilowatts
		Line on			
395	16.5	0.40	80.5	0.077	0.10
435	17.9	0.60	90.5	0.087	0.13
490	20.5	0.70	101.6	0.101	0.17
535	22.6	0.80	111.1	0.112	0.22
590	24.7	1.00	120.4	0.119	0.28
635	27.1	1.10	130.2	0.135	0.35
680	29.2	1.40	139.2	0.145	0.45
735	31.6	1.80	150.0	0.158	0.68
780	33.4	2.40	159.0	0.169	1.10
812	35.3	3.30	165.8	0.178	1.80
830	36.3	3.60	169.0	0.181	2.40
862	37.5	5.12	176.6	0.190	3.60
893	39.2	6.35	183.2	0.199	4.70
914	40.5	7.50	187.0	0.207	6.00
975	43.9	11.40	200.0	0.227	9.30
1020	47.8	14.50	209.0	0.243	12.60
1050	49.3	17.00	214.2	0.253	14.60
1080	52.7	19.50	220.2	0.267	17.60
1125	55.5	22.80	223.4	0.283	20.30
		Line off			
400	1.14	0.40	80.0	0.005	0.055
500	1.37	0.62	100.5	0.007	0.10
600	1.63	0.82	121.5	0.008	0.15
718	1.87	1.18	143.5	0.010	0.21
812	2.05	1.45	161.0	0.011	0.28
905	2.29	1.80	181.0	0.013	0.35
1015	2.69	2.20	202.2	0.015	0.44
1095	3.25	3.64	217.0	0.017	0.54

Weather

Cloudy—rain in morning. Barometer 75 cm.—Temperature, wet 10 deg. cent. dry 12 deg. cent.

Line and connections

(1 and 3)—(2 and 4) Ground wires in place.

Total conductor length.....109,500 cm.

Spacing.....310 cm.

No. 3/0 seven-strand cable—diameter.....1.18 cm.

Transformer ratio.....1000/200,000

Frequency.....60 cycles.

Digitized by Google

Fig. 1 shows the characteristic corona curves. The corrected values for Table I are recorded in Table II.

TABLE II
CORONA LOSS
OBSERVED VALUES CORRECTED FROM TABLE 1

Kilovolts between lines e'	Line amperes	Kilovolts to neutral e	Kilowatts line loss p	KV-A	Power factor
80.5	0.072	40.2	——	5.80	——
90.5	0.081	45.2	——	7.33	——
101.6	0.094	50.8	——	9.55	——
111.1	0.104	55.5	——	11.55	——
120.4	0.111	60.2	0.11	13.40	0.008
130.2	0.126	65.1	0.15	16.40	0.009
139.2	0.135	69.6	0.22	18.80	0.012
150.0	0.147	75.0	0.40	22.10	0.18
159.0	0.157	79.5	0.79	25.00	0.032
165.8	0.166	82.9	1.42	27.60	0.051
169.0	0.168	84.5	2.04	28.40	0.072
176.6	0.177	88.3	3.21	31.20	0.103
183.2	0.185	91.6	4.28	33.90	0 126
187.0	0.193	93.5	5.55	36.10	0.154
200.0	0.212	100.0	8.78	42.40	0.207
209.0	0.227	104.5	12.02	47.50	0.253
214.2	0.237	107.1	13.99	50.70	0.276
220.2	0.250	110.1	16.94	55.10	0.307

The shape of the curve between kilovolts and kilowatts suggests a parabola. After trial it was found that the losses above the knee of the curve follow a quadratic law. Below the knee it was found that the curve deviates from the quadratic law. This variation near the critical voltage is due to dirt spots, irregularities and other causes that will be discussed in section VII. We will confine ourselves in this section to the main part of the curve expressed by

$$p = c^2 (e - e_0)^2$$

where

p = the line loss.

e = kilovolts to neutral.

e_0 is called the *disruptive critical voltage*, and is measured in kilovolts to neutral.

The meaning of e_0 and c^2 will be considered later.

Digitized by Google

Let us now see the best mechanism of evaluation of constants for a given set of tests. We may write (1)

$$\sqrt{p} = c\,(e - e_0)$$

then if the quadratic law holds the curve between the square root of p, and e will be a straight line. e_0 will be the point where the line cuts the e axis, and c will be the slope of the line (see Fig. 15). e_0 and c might be evaluated graphically in this

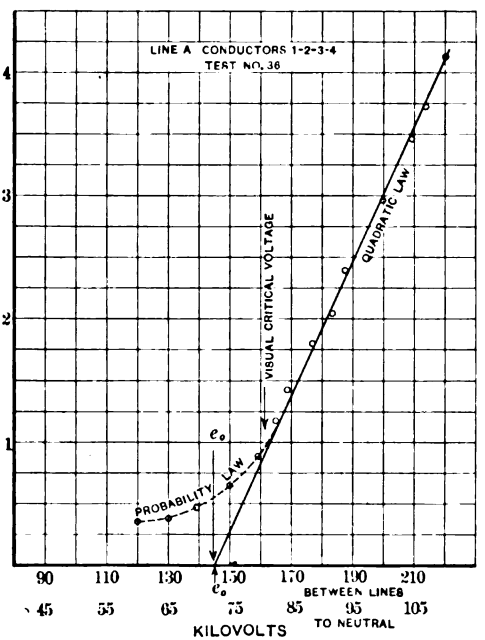


FIG. 15.—Corona loss—method of reducing ,

way, but it is difficult to know how to draw the line accurately and give each point the proper weight. To do this we will use the $\Sigma\triangle$ method,* and proceed as follows:

The values of e and the $\sqrt{p}$ for the set of readings to be investigated are first tabulated and a curve plotted (Fig. 15). All points that differ greatly from the straight line are eliminated as probably in error or, as at the lower part of the curve, following a different law. Then taking the remaining

*See Engineering Mathematics, Steinmetz, page 232.

Digitized by Google

readings and forming two groups each of an equal number of readings we have:

$$\text{Group 1} \quad \Sigma_1 e \qquad \Sigma_1 \sqrt{p}$$

$$\text{Group 2} \quad \Sigma_2 e \qquad \Sigma_2 \sqrt{p}$$

Then

$$\triangle \Sigma e = \Sigma_1 e - \Sigma_2 e \qquad \triangle \Sigma \sqrt{p} = \Sigma_1 \sqrt{p} - \Sigma_2 \sqrt{p}$$

$$\Sigma \Sigma e = \Sigma_1 e + \Sigma_2 e \qquad \Sigma \Sigma \sqrt{p} = \Sigma_1 \sqrt{p} + \Sigma_2 \sqrt{p}$$

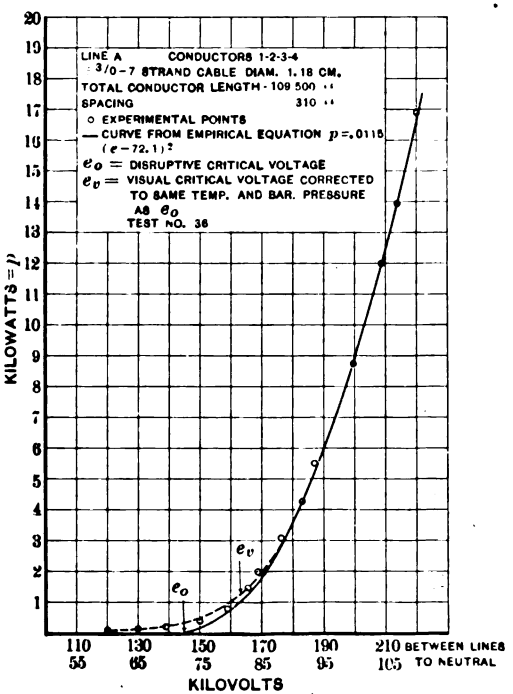


FIG. 16.—Corona loss

$$c = \frac{\triangle \Sigma \sqrt{p}}{\triangle \Sigma e}$$

$$e_0 = \frac{\Sigma \Sigma e - \frac{\Sigma \Sigma \sqrt{p}}{c}}{n}$$

where n is the number of points used.

Thus e_0 and c are determined.

Digitized by Google

TABLE III

CORONA LOSS

METHOD OF REDUCING (10-6-10)

Kilovolts between lines e'	Kilovolts to neutral e	Kw. p	$\sqrt{p}$
120.4	60.2	0.11	0.332
130.2	65.1	0.15	0.388
139.2	69.6	0.22	0.470
150.0	75.0	0.40	0.632
159.0	79.5	0.79	0.889
165.8	82.9	1.42	1.192
169.0	84.5	2.04	1.428
176.6	88.3	3.21	1.792
183.2	91.6	4.28	2.069
187.0	93.5	5.55	2.356
200.0	100.0	8.78	2.963
209.0	104.5	12.02	3.467
214.2	107.1	13.99	3.740
220.2	110.1	16.94	4.116

Total conductor length.....109,500 cm.

Spacing.....310 cm.

No. 3/0 seven-strand cable diameter.....1.18 cm.

e	$\sqrt{p}$
91.6	2.069
93.5	2.356
100.0	2.963
104.2	3.467
107.1	3.740
110.1	4.116

$\Sigma_2 e = 285.1$ $\Sigma_2 \sqrt{p} = 7.388$

$\triangle \Sigma e = 36.6$ $\triangle \Sigma \sqrt{p} = 3.935$

$\Sigma \Sigma e = 606.8$ $\Sigma \Sigma \sqrt{p} = 18.711$

$$c = \frac{\triangle \Sigma \sqrt{p}}{\triangle \Sigma e} = 0.107$$

$$c^2 = 0.0115$$

$$e_0 = \frac{\Sigma \Sigma e - \frac{\Sigma \Sigma \sqrt{p}}{c}}{n}$$

$\Sigma_1 e = 321.7$ $\Sigma_1 \sqrt{p} = 11.323$

$e_0 = 72.1$

$e_0' = 144.2$

Table III shows the method of reducing. The curve, Fig. 16, is drawn from the equation $p = 0.0115\ (e - 72.1)^2$. The circles show the experimental values, and where the losses deviate from the quadratic law.

Digitized by Google

TABLE IV

CALCULATED VALUES FOR FIG. 16

$$p = c^2 (e - e_0)^2$$

$$p = 0.0115 (e - 72.1)^2$$

Kilovolts between lines e'	Kilovolts to neutral e	Kilowatts $p = c^2 (e - e_0)^2$
144.2	71.2	0.0
150.0	75.0	0.10
159.0	79.5	0.63
165.8	82.9	1.34
169.0	84.5	1.77
176.6	88.3	3.02
183.2	91.6	4.17
187.0	93.5	5.08
200.0	100.0	9.03
209.0	104.5	12.10
214.2	107.1	14.10
220.2	110.1	16.70

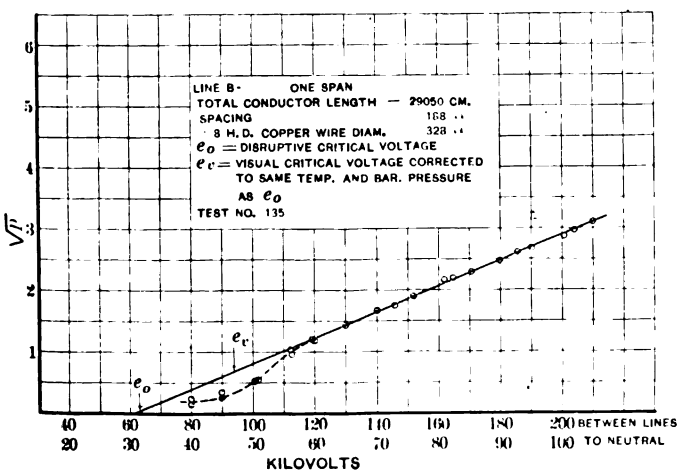

LINE B- ONE SPAN
TOTAL CONDUCTOR LENGTH — 29050 CM.
SPACING 168 "
8 H. D. COPPER WIRE DIAM. 328 "
e_o = DISRUPTIVE CRITICAL VOLTAGE
e_v = VISUAL CRITICAL VOLTAGE CORRECTED TO SAME TEMP. AND BAR. PRESSURE AS e_o
TEST NO. 135
$\sqrt{p}$
e_v
e_o
40 60 80 100 120 140 160 180 200 BETWEEN LINES
20 30 40 50 60 70 80 90 100 TO NEUTRAL
KILOVOLTS

FIG. 17.—Corona loss—Method of reducing

Table V gives a similar set of data for a small wire. The results are plotted in Figs. 17 and 18.

All data taken under various conditions was first reduced in this way and tabulated as in Table VI, (*a*), (*b*) (*c*).

Digitized by Google

TABLE V

CORONA LOSS

Σ △ METHOD OF REDUCING

Kilovolts between lines e'	Kilovolts to neutral e	Kilowatt line loss p	$\sqrt{p}$
70.0	35.0	0.02	0.14
80.0	40.0	0.07	0.26
91.2	45.6	0.26	0.51
101.3	50.6	0.85	0.92
110.0	55.0	1.42	1.19
120.0	60.0	2.02	1.42
130.0	65.0	2.71	1.65
141.5	70.7	3.51	1.87
70.0	35.0	0.06	0.24
80.0	40.0	0.10	0.32
90.5	45.2	0.26	0.51
101.3	50.6	0.96	0.98
109.9	54.9	1.43	1.20
152.0	76.0	4.45	2.11
160.4	80.2	5.17	2.27
170.0	85.0	6.06	2.46
180.6	90.3	7.04	2.65
190.6	95.3	8.26	2.87
200.0	100.0	9.52	3.08
193.6	96.8	8.60	2.93
176.0	88.0	6.65	2.58
155.0	77.5	4.66	2.16
136.0	68.0	3.01	1.73

Total conductor length ..... 29,050 cm.
Spacing ..... 183 cm
No. 8 H. D. copper wire—diameter ..... .328 cm.

e	$\sqrt{p}$	e	$\sqrt{p}$
100.0	3.08	80.2	2.27
96.8	2.93	77.5	2.15
95.3	2.87	68.0	1.73
90.3	2.65	60.0	1.42
85.0	2.46	88.0	2.58
467.4	13.99	373.7	10.16

$\Sigma\Sigma e = 841.1$

$\Sigma\Sigma \sqrt{p} = 24.15$

$$e_0 = 84.11 - \frac{24.15}{\frac{0.0406}{10}}$$

$= 24.6$

$\triangle \Sigma e = 93.7$

$\triangle \Sigma \sqrt{p} = 3.80$

$$c = \frac{3.80}{93.7} = 0.0406 \qquad c^2 = 0.00164 \qquad p = 0.00164\,(e - 24.6)^2$$

Digitized by Google

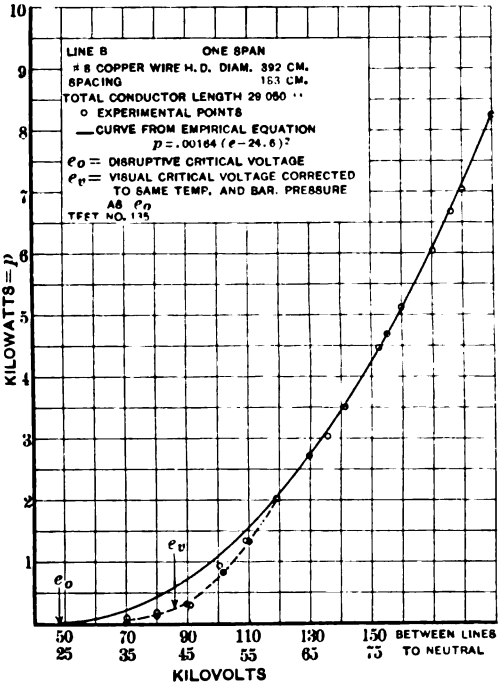

LINE B ONE SPAN
8 COPPER WIRE H.D. DIAM. 392 CM.
SPACING 153 CM.
TOTAL CONDUCTOR LENGTH 29 050 ''
o EXPERIMENTAL POINTS
—CURVE FROM EMPIRICAL EQUATION
$p = .00164 (e - 24.6)^2$
e_o = DISRUPTIVE CRITICAL VOLTAGE
e_v = VISUAL CRITICAL VOLTAGE CORRECTED TO SAME TEMP. AND BAR. PRESSURE AS e_o
TEST NO. 135
KILOWATTS = p
KILOVOLTS
50 70 90 110 130 150 BETWEEN LINES
25 35 45 55 65 75 TO NEUTRAL

FIG. 18—Corona loss

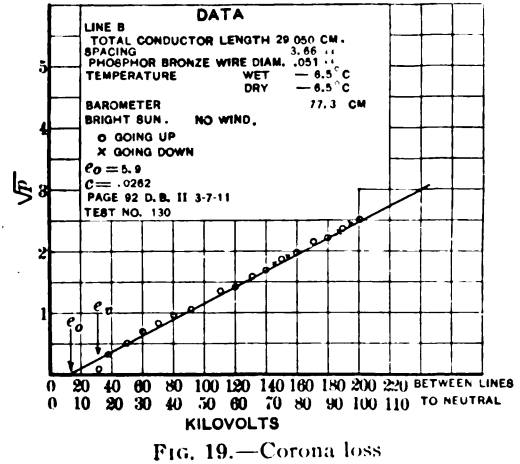

DATA
LINE B
TOTAL CONDUCTOR LENGTH 29 050 CM.
SPACING 3.66 ''
PHOSPHOR BRONZE WIRE DIAM. .051 ''
TEMPERATURE WET — 6.5°C
DRY — 6.5°C
BAROMETER 77.3 CM
BRIGHT SUN. NO WIND.
o GOING UP
x GOING DOWN
$e_o = 5.9$
$C = .0262$
PAGE 92 D.B. II 3-7-11
TEST NO. 130
$\sqrt{p}$
KILOVOLTS
0 20 40 60 80 100 120 140 160 180 200 220 BETWEEN LINES
0 10 20 30 40 50 60 70 80 90 100 110 TO NEUTRAL

FIG. 19.—Corona loss

Digitized by Google

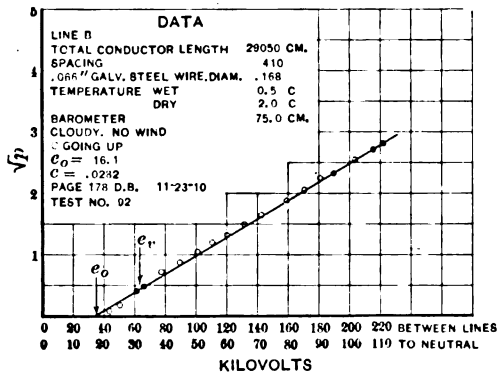


FIG. 20. - Corona loss

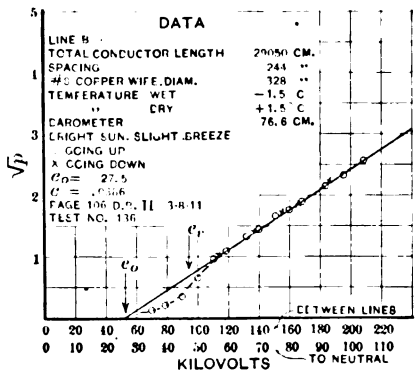


FIG. 21.—Corona loss

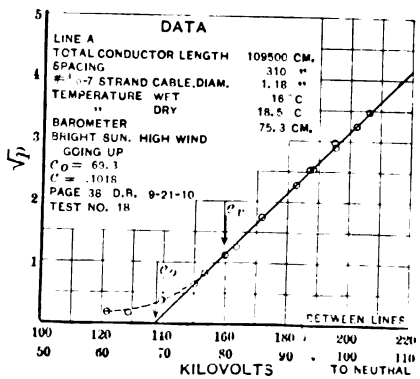


FIG. 22.—Corona loss

Digitized by Google

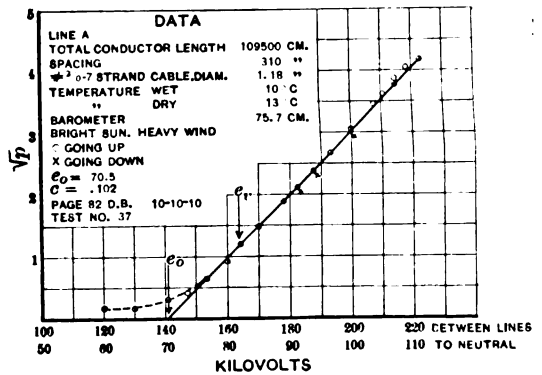


FIG. 23.—Corona loss

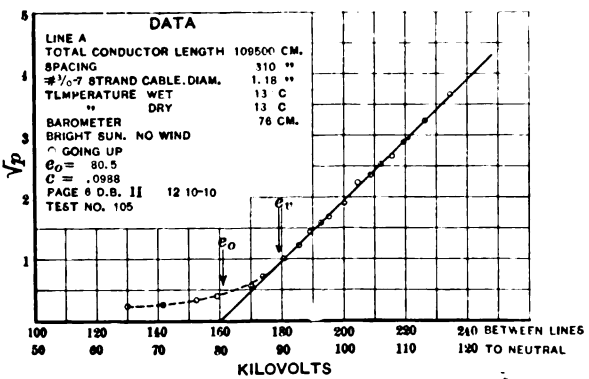


FIG. 24.—Corona loss

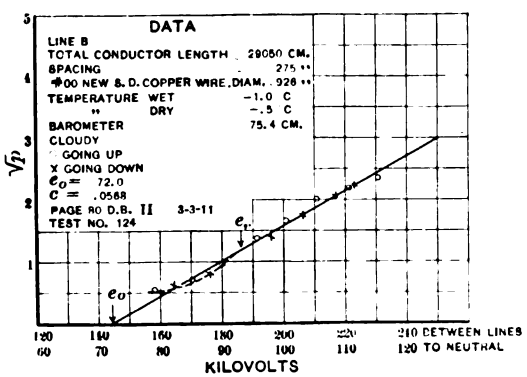


FIG. 25.—Corona loss

Digitized by Google

TABLE VIa

Σ △ REDUCTION OF CORONA TESTS
CABLES

Test No.	Temperature Wet	Temperature Dry	Bar cm.	Freq. cycles	$c^2 f$ per cm. of total cond.	e_0	g_0 E.f	g_0 max.	c^2/f at 25° C. 76 cm. bar	g_0 max. at 25° C. 76 cm. bar	Spacing cm.	Weight Limits		No. points used	Weather
STANDARD—Line A—Conductors 1-2-3-4. Total length 10,500 cm. No. 3/0 7-strand copper cable diameter 1.18 cm.															
18	16	18.5	75.5	60	15.80×10^{-10}	69.3	18.9	26.1	16.10×10^{-10}	25.5	310	160	206	8	Bright sun—wind.
36	10	12	75.6	60	17.57 "	72.1	19.5	26.9	18.20 "	26.0	310	180	220	6	Cloudy.
37	10	13	75.7	60	15.80 "	70.5	19.05	26.3	16.48 "	25.3	310	164	222	16	Bright sun. Heavy wind.
84	1	3	75.2	60	15.80 "	74.5	20.1	27.8	16.93 "	25.8	310	168	213	4	Cloudy.
101	− 1	− 1	74.7	60	15.88 "	76.9	20.7	28.6	17.17 "	26.5	310	170	211	6	Cloudy.
103	− 4.9	− 4.5	75.7	60	16.24 "	77.7	21.0	29.0	18.03 "	26.1	310	174	221	8	Sun—heavy wind.
104	− 9.5	− 9.5	76.2	60	14.93 "	78.5	21.2	29.3	17.00 "	25.7	310	177	233	14	Sun—cold wind.
105	−13	−13	76.2	60	14.84 "	80.5	21.7	30.0	17.15 "	26.0	310	181	234	12	Bright sun. No wind Snow on ground.
109	− 3	− 2	73.9	60	14.48 "	74.4	20.1	27.8	15.61 "	25.8	310	160	214	12	Hazy sun. Slight wind Snow on ground.
119	− 6.5	− 6	76.5	60	12.00 "	75.1	20.3	28.0	13.51 "	24.8	310	171.2	217.6	8	Bright sun. Heavy wind Going up—frost on lines.
119	− 6.5	− 6	76.5	60	16.56 "	78.3	21.2	29.3	18.65 "	25.9	310	174.4	215.4	4	Bright sun. Heavy wind. Going down. Lines dried by current.
Line *B*—Total conductor length 29,050 cm. 0.375" galv. steel cable diameter 0.953 cm.															
100	− 1	− 1	74.7	60	26.40×10^{-10}	50.0	20.0	27.6	28.55×10^{-10}	25.5	91.4	161	212	8	Cloudy.
115	− 7.8	− 7	76.5	60	30.40 "	54.7	21.4	29.5	34.40 "	26.2	91.4	160	207.6	10	Bright sun—heavy wind.
Line *B*—Total conductor length 29,050 cm. 0.230" galv. steel cable diameter 0.585 cm.															
73	1	3	75.2	60	16.96×10^{-10}	34.7	20.6	28.7	18.20×10^{-10}	26.5	91.4	140	156	4	Cloudy.
80	1	3	75.2	60	13.08 "	34.3	18.7	25.8	14.04 "	24.0	152	181	213	4	"
77	1	3	75.2	60	9.08 "	37.9	18.6	25.7	9.76 "	23.9	310	160	221	6	"
82	1	3	75.2	60	8.56 "	41.5	19.4	26.8	9.20 "	25.0	432	180	210	4	"

Digitized by Google

TABLE VI*b*

Σ △ REDUCTION OF CORONA TESTS
LINE *B* WIRES

Test No.	Temperature Wet	Temperature Dry	Bar cm.	Freq. cycles	c^2/f per cm. of total cond.	e_0	g_0 Eff	g_0 max.	c^2/f at 25° C. 76 cm. bar	g_0 max. at 25° C. 76 cm. bar	Spacing cm.	Weight Limits		No. points used	Weather
0.02″ phosphor bronze wire—diameter 0.051 cm.										Total conductor length cm.					
129	—	— 8	77.3	60	——	5.3	24.6	33.9	——	29.8	122	90.5	173.8	14	Bright sun—no wind.
133	—	— 1.5	77.3	60	——	5.5	24.1	33.2	——	29.8	183	91.0	203	12	" "
131	—	— 8	77.3	60	——	5.8	24.6	33.9	——	29.8	244	109.7	203	18	" "
130	—	— 6.5	77.3	60	——	5.9	24.5	33.8	——	29.8	366	100	201	14	" "
132	—	— 1.5	77.3	60	——	6.0	24.1	33.2	——	29.8	488	102	210	16	" "
0.066-in. galvanized steel wire—diameter 0.168 cm.										Total conductor length 29,050 cm.					
91	0.5	2.0	75.0	60	8.44×10^{-10}	15.5	24.4	33.7	9.07×10^{-10}	31.3	152	101	218	8	" "
94	0.5	2.0	75.0	60	6.84 "	16.4	24.6	33.9	7.34 "	31.6	229	118	222	6	" "
92	0.5	2.0	75.0	60	4.28 "	16.1	22.7	31.3	4.60 "	29.1	410	131	222	8	Cloudy—no wind.
95	1.0	3.0	75.0	60	4.68 "	18.0	24.4	33.7	5.00 "	31.4	550	120	222	6	" "
No. 8 copper wire H. D. Diameter 0.328 cm.										Total conductor length 29,050 cm.					
134	— 1.5	+ 1.5	76.6	60	12.89×10^{-10}	25.2	22.9	31.6	14.11×10^{-10}	28.8	122	112	201	16	Bright sun. Slight breeze
135	— 1.5	+ 1.5	76.6	60	9.52 "	24.6	21.5	29.7	10.42 "	27.1	183	120	200	10	" "
136	— 1.5	+ 1.5	76.6	60	8.56 "	27.5	23.0	31.7	9.38 "	29.0	244	110.5	203.8	10	" "
137	— 1.5	+ 1.5	76.6	60	6.52 "	26.4	20.4	28.1	7.14 "	25.7	366	124	186	10	" "
138	— 1.5	+ 1.5	76.6	60	5.52 "	26.0	20.1	27.7	6.05 "	25.2	488	131.5	202.2	10	" "
No. 4 copper wire H. D. diameter 0.518 cm.										Total conductor length 29,050 cm.					
125	— 5	— 4.5	75.9	60	17.88×10^{-10}	34.7	22.7	31.3	19.85×10^{-10}	28.2	91.4	128	213	16	Cloudy. Slight breeze.
126	— 5	— 4.5	75.9	60	11.44 "	36.3	21.3	29.4	12.70 "	26.5	183	151	231	12	" "
127	— 3.5	— 2.5	75.9	60	8.68 "	37.5	20.7	28.6	9.57 "	26.0	275	159.2	216	10	" "
128	— 2	— 1.5	75.9	60	6.88 "	40.0	20.0	27.6	7.64 "	26.2	397	170	221	8	" "
No. 2 0 copper wire S. D. Diameter 0.926 cm.										Total conductor length 29,050 cm.					
122	— 1	— 0.5	75.4	60	23.80×10^{-10}	55.3	22.6	31.2	25.85×10^{-10}	28.7	91.4	185.6	233	10	Cloudy.
123	— 1	— 0.5	75.4	60	19.80 "	66.3	23.9	33.0	21.51 "	30.4	183	191	225	8	"

Digitized by Google

TABLE VIc

Σ Δ REDUCTION—DIFFERENT FREQUENCIES. CORONA TESTS

Test No.	Temperature Wet	Temperature Dry	Bar cm.	Freq. cycles	$c^2 f$ per cm. of total cond.	e_0	g_0 Eff	g_0 max.	c^2/f at 25° C. 76 cm. bar	g_0 max. at 25° C. 76 cm. bar	Spacing cm.	Weight Limits		No. points used	Weather
Line A—conductors 1-2-3-4. Total length 109,500 cm. No. 3/0 7-strand copper cable diameter 1.18 cm.															
14	20	22	75.2	50	17.20×10^{-10}	69.3	18.7	25.8	17.26×10^{-10}	25.7	310	164	195	6	Fair—sun at intervals.
15	20	22	75.2	60	17.48 "	70.0	18.9	26.1	17.54 "	25.9	310	161	202	6	" "
17	20	22	75.2	70	18.77 "	70.5	19.0	26.2	18.83 "	26.1	310	163	200	6	" "
16	20	22	75.2	80	17.20 "	69.5	18.75	25.9	17.26 "	25.8	310	158	190	4	" "
33	20	22	76.2	90	17.91 "	68.2	18.4	25.4	18.21 "	25.0	310	153	188	4	Cloudy.
Line A conductors 2-3 total length 54,750 cm. No. 3/0 seven-strand copper cable diameter 1.18 cm.															
68	3	5	75.2	47	11.40×10^{-10}	72	19.5	26.9	12.16×10^{-10}	25.3	310	170	197	4	Damp and Cloudy.
69	3	5	75.2	60	12.42 "	70.2	19.0	26.2	13.30 "	24.6	310	170	212	6	" "
62	3	5	75.2	80	13.78 "	71.5	19.2	26.5	14.68 "	24.9	310	183	213	4	" "
65	3	5	75.2	90	13.88 "	73.2	19.8	27.3	14.80 "	25.6	310	180	211	4	" "
66	3	5	75.2	100	13.14 "	72.2	19.5	26.9	14.02 "	25.2	310	179	211	6	" "

Digitized by Google

To further investigate the law it is now necessary to determine the various factors effecting e_0 and c^2. These will be taken up under separate headings. The loss near the critical point will then be discussed.

In Fig. 19 the $\sqrt{p}$ and e are plotted. This is an especially interesting curve on account of its range. The measurements are taken up to 20 times the disruptive critical voltage, and show how well the quadratic law holds. Figs. 20 to 25 are plotted in the same way to illustrate the quadratic law.

IV. Frequency

To determine the way that frequency enters into the power equation:

$$p = c^2 (e - e_0)^2$$

a series of loss curves were taken at various frequencies between 47 and 115 cycles. Points taken from the volt-watt curves are tabulated below in Table VII and VIII and plotted in Figs. 26 and 27.

TABLE VII

LINE A. CONDUCTORS 2-3. TOTAL LENGTH 54,750 cm.

	210	200	190	180 kilovolts between lines
		Kilowatts loss		
f				
47	4.9	3.2	2.0	1.30
60	5.1	3.7	2.6	1.6
70	6.1	4.3	2.8	1.70
80	6.9	5.0	3.4	1.9
			3.6	2.1
90	7.5	5.6	3.8	2.6
100	8.0	5.6	3.70	2.4
115	9.3	7.1	5.0	3.4

TABLE VIII

LINE A. CONDUCTORS 1-2-3-4. TOTAL LENGTH 109,500 cm.

	210	200	190	180 kilovolts between lines
		Kilowatts Loss		
f				
50	9.24	6.30	3.80	2.20
60	10.50	7.30	4.65	2.65
70	12.1	8.60	5.50	3.20
80	14.0	10.20	6.80	3.95

Digitized by Google

For a given voltage the points lie on a straight line through the zero point. That is, the loss seems to vary directly with the

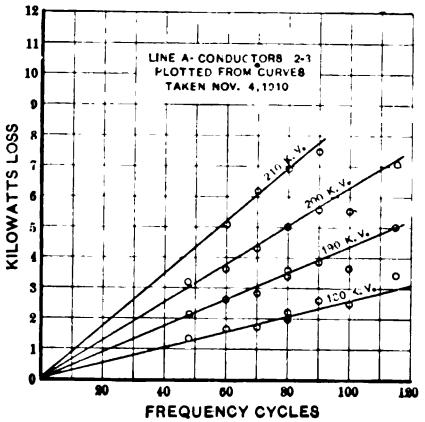


FIG. 26.—Corona loss different frequencies

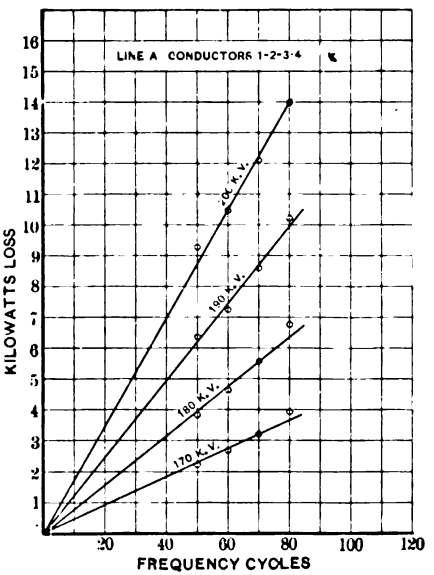


FIG. 27.—Corona loss—Different frequencies

frequency. The data is further investigated and reduced by the $\Sigma\,\Delta$ method. The results are tabulated below in Tables IX and X.

Digitized by Google

TABLE IX
LINE A. CONDUCTORS 2-3

f	e_0	c^2	Total $c^2/f=a$
47	72	0.00292	6.00×10^{-5}
60	70.2	0.00408	6.80
80	71.5	0.00600	7.50
90	73.2	0.00684	7.60
100	72.2	0.0072	7.20
		Average,	7.10

TOTAL LENGTH 54,750 cm.

TABLE X
LINE A. CONDUCTORS 1-2-3-4. TOTAL LENGTH 109,500 cm.

f	e_0	c^2	Total $c^2/f=a$
50	69.3	0.0094	18.80×10^{-5}
60	70.0	0.0115	19.10
70	70.5	0.0140	20.60
80	69.5	0.0151	18.80
90	68.2	0.0177	19.60
		Average,	19.40

The values of c^2/f should be constant if the loss varies directly as the frequency. The tables show c^2/f constant within the limits of experimental error.

Care was taken to keep the wave shape as nearly constant as possible in these tests. Variations in e_0 and c^2 are accounted for by wave shape changes. For instance a slight progressive change in the wave shape would change the slope c of the line between $\sqrt{p}$ and e. This would cause a variation in both e_0 and c^2.

The reduced values of c^2 are plotted with frequency in curves 28 and 29. The points lie on a straight line passing through the zero point. The tabulated values show that e_0 is independent of the frequency. The power equation may now be written:

$$p=af(e-e_0)^2$$

that is, at a given sine wave voltage the loss per cycle is constant for a given conductor at a given spacing.

Digitized by Google

The fact that the curves pass through the zero point does not necessarily mean that there is no loss at zero frequency or continuous impressed voltage. What takes place is probably this: When excessive continuous voltages are applied to a conduc-

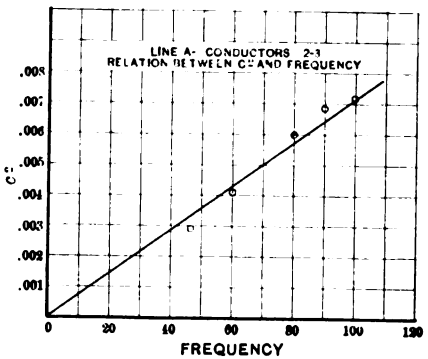


FIG. 28.—Corona loss

tor, the air is broken down and a transfer of energy which appears as corona takes place. Now if the conditions were constant, such as still air, constant temperature, and no electrostatic repulsion, there would be no further loss than the first energy

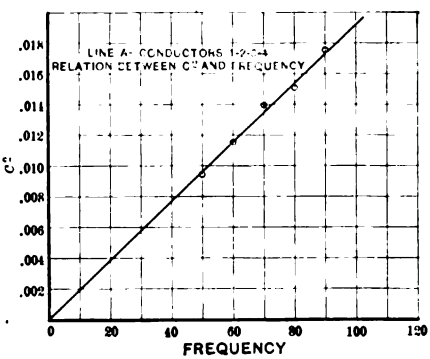


FIG. 29.—Corona loss

rush. However, as this over strained air is probably driven away and replaced by fresh air, which is in turn broken down, there is actually a power loss with continuous voltage. Hence the above frequency relations do not contradict the observed fact of corona loss with direct current. If observations could

Digitized by Google

be made at very low frequencies, or continuous impressed voltage, the curve would probably be obtained as shown in Fig. 30.

V. Relation Between $c^2/f=a$ and s/r

The power equation may now be written:

$$p=a f (e-e_0)^2$$

where $a=c^2/f$ is a factor that has not to this point been investigated.

In Table XI are values of c^2/f for various sizes of wire and cable and various spacings. Upon investigation it is found that a varies greatly with the radius of the conductor and the spacing. Plotting s/r and a a curve is obtained that suggests a hyperbola.

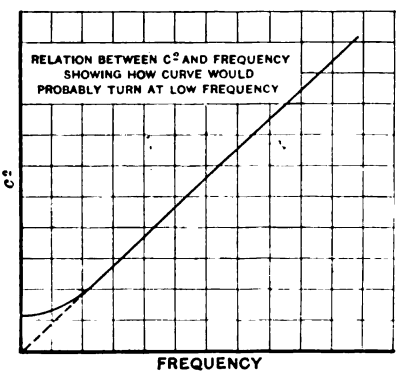


Fig. 30.—Corona loss

Where: r = the radius of the conductor in cm., s = distance between conductor centers. The curve between log a and log s/r is a straight line. Therefore the following relation between a and s/r is established.

$$a=c^2/f=k\,(s/r)^d$$

The constants k and d are calculated by the $\Sigma\,\Delta$ method in Table XII, and:

$$a=c^2/f=3.70\,(r/s)^{.523}\times 10^{-8} \qquad (2)$$

These calculations are just preliminary.

Digitized by Google

The fair weather value of a for standard line A 1-2-3-4 may now be examined in Table XIII.

It is seen that these values are not exactly constant, but apparently vary with the temperature and barometric pressure. $1/\delta$ in Table XIII is explained in section XI. It is sufficient here to call it the air density correction factor, it is unity at

TABLE XI
(EXPERIMENTAL VALUES FROM TABLE VI)

Relation between $e^2/f = a$ and s/r

Tests No.	Diam. cm.	$\frac{s}{r}$	$e^2 f \times 10^{10} = a \times 10^{10}$	Style of conductor	Material
93	0.168	6550	4.68	Wire	Gal. iron
92	0.168	4880	4.28	"	"
86	0.168	3700	5.44	"	"
138	0.328	2980	5.52	"	Copper
94	0.168	2730	6.84	"	Gal. iron
137	0.328	2230	6.52	"	Copper
91	0.168	1820	8.44	"	Gal. iron
128	0.518	1530	6.87	"	Copper
136	0.328	1490	8.56	"	"
82	0.585	1480	8.56	Cable	Gal. iron
135	0.328	1120	9.52	Wire	Copper
94a	0.168	1090	10.56	"	Gal. iron
77	0.585	1060	9.08	Cable	"
79	0.585	770	9.52	"	"
134	0.328	740	12.88	Wire	Copper
126	0.518	700	11.44	"	"
18	1.181	525	15.80	Cable	"
80	0.585	520	13.08	"	Gal. iron
125	0.518	350	17.88	Wire	Copper
73	0.585	310	16.96	Cable	Gal. iron
100	0.953	193	26.40	"	"

25 deg. cent. and 76 barometer. a and $1/\delta$ in curve Fig. 31 suggest that a varies as $1/\delta$. Multiplying by $1/\delta$ then, reduces a to the standard temperature of 25 deg. cent. and 76 cm. barometric pressure. The constants for equation (2) were determined from values of a corresponding to various temperatures and barometric pressures. In order to properly evaluate the constants it is now necessary to reduce all a values

Digitized by Google

TABLE XII

RELATION OF $\frac{s}{r}$ to a. $\Sigma \triangle$ REDUCTION

Test No.	Diam. cm.	$\frac{s}{r}$	$\left(\frac{c^2}{f}\times 10^{10}\right)$ per cm. $= a \times 10^{10}$	$\log \frac{s}{r}$	$\log_e\left(\frac{c^2}{f}\times 10^{10}\right)$	Kind of cond.	Material
92	0.168	4880	4.28	8.492	1.454	Wire	Gal. iron
86	0.168	3700	5.44	8.215	1.694	"	"
138	0.328	2980	5.52	8.000	1.708	"	Copper
137	0.328	2230	6.52	7.709	1.875	"	"
136	0.328	1490	8.56	7.306	2.147	"	"
82	0.585	1480	8.56	7.299	2.147	Cable	Gal. iron
135	0.328	1120	9.52	7.020	2.253	Wire	Copper
94a	0.168	1030	10.56	6.993	2.357	"	Gal. iron
134	0.328	740	12.88	6.607	2.556	"	Copper
126	0.518	700	11.44	6.551	2.437	"	"
18	1.181	525	15.80	6.263	2.760	Cable	"
80	0.585	520	13.08	6.254	2.575	"	Gal. iron
125	0.518	350	17.88	5.858	2.821	Wire	Copper
73	0.585	310	16.96	5.736	2.831	Cable	Gal. iron

$$\Sigma \log \frac{s}{r} = 54.04 \qquad \Sigma \log (c^2/f \times 10^{10}) = 13.284$$

$$\Sigma \log \frac{s}{r} = 44.26 \qquad \Sigma \log (c^2/f \times 10^{10}) = 18.400$$

$$\triangle \Sigma \log \frac{s}{r} = 9.78 \qquad \triangle \Sigma \log (c^2/f \times 10^{10}) = 5.116$$

$$\Sigma \Sigma \log \frac{s}{r} = 98.30 \qquad \Sigma \Sigma \log (c^2/f \times 10^{10}) = 31.67$$

$$d = \frac{\triangle \Sigma \log (c^2/f \times 10^{10})}{\log \frac{s}{r}} = -0.523$$

$$c' = \frac{\Sigma \Sigma \log (c^2/f \times 10^{10}) - d \Sigma \Sigma \log \frac{s}{r}}{n} = 5.91$$

$$-0.523 \log \frac{s}{r} = \log (c^2/f \times 10^{10}) - 5.91$$

$$(c^2/f) = 3.70 \left(\frac{r}{s}\right)^{0.523} \times 10^{10}$$

Digitized by Google

to a standard value of temperature and barometric pressure. In Table XIV all values of a are corrected to 25 deg. cent. and 76 cm. barometer, and the constants recalculated by the $\Sigma\,\Delta$ method in Table XV.

TABLE XIII

RELATION OF a TO $\frac{1}{\delta}$ FOR MAIN EXPERIMENTAL LINES

(STANDARD LINE A)
Line A 1-2-3-4

Test No.	$(c^2/f)\times10^{10}$ per cm.	δ	$\frac{1}{\delta}$
18	15.80	0.982	1.020
36	17.56	0.966	1.037
37	15.80	0.959	1.043
84	15.80	0.933	1.074
101	15.88	0.925	1.081
103	16.24	0.901	1.112
104	14.92	0.878	1.138
105	14.84	0.866	1.158
109	14.48	0.928	1.078
119	16.56	0.888	1.127

TABLE XIV

$\frac{a}{\delta}$ and $\frac{s}{r}$

Test No.	Diam. cm.	s/r	$\frac{c^2}{f}\times10^{10}=(a\times10^{10})$	$\frac{c^2}{f}\times\frac{10^{10}}{\delta}$	Corr. factor	$\log\frac{c^2}{f}\times\frac{10^{10}}{\delta}$	$\log_e\frac{s}{r}$	Style of conductor
95	0.168	6550	4.68	5.00	0.936	1.609	8.787	Wire
92	0.168	4880	4.28	4.60	0.932	1.526	8.492	"
86	0.168	3700	5.44	5.80	0.930	1.758	8.215	"
138	0.328	2980	5.52	6.04	0.913	1.798	8.000	"
137	0.328	2230	6.52	7.16	0.913	1.968	7.709	"
77	0.585	1060	9.08	9.76	0.932	2.278	6.966	Cable
126	0.518	700	11.44	12.72	0.898	2.543	6.551	Wire
18	1.181	525	15.80	16.08	0.982	2.777	6.263	Cable
80	0.585	520	13.08	14.00	0.932	2.639	6.254	"
125	0.518	350	17.88	19.88	0.898	2.989	5.858	Wire
73	0.585	310	16.96	18.20	0.932	2.901	5.736	Cable
100	0.953	193	26.40	28.52	0.925	3.341	5.263	

Digitized by Google

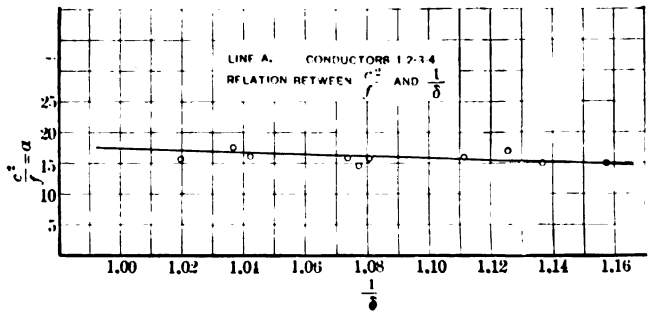


FIG. 31.—Corona loss

TABLE XV

$\Sigma\,\Delta$ REDUCTION OF RELATION OF c^2/f TO $\frac{s}{r}$

c^2/f CORRECTED TO 25 DEG. CENT.—76 CM. BAROMETRIC PRESSURE

Test No.	$\log_e\left((c^2/f)\times\frac{10^{10}}{\delta}\right)$	$\log\frac{s}{r}$	Test No.	$\log\left((c^2/f)\times\frac{10^{10}}{\delta}\right)$	$\log\frac{s}{r}$
95	1.609	8.787	126	2.543	6.551
92	1.526	8.492	18	2.777	6.263
86	1.758	8.215	80	2.639	6.254
138	1.798	8.000	125	2.989	5.858
137	1.968	7.709	73	2.901	5.736
77	2.278	6.966	100	3.341	5.263
	10.94	48.169		17.20	35.925

$$\Delta\,\Sigma\log\left((c^2/f)\times\frac{10^{10}}{\delta}\right)=-6.260$$

$$\Sigma\,\Sigma\log\left((c^2/f)\times\frac{10^{10}}{\delta}\right)=-28.14$$

$$\Delta\,\Sigma\log\frac{s}{r}=12.244$$

$$\Sigma\log\frac{s}{r}=84.094$$

$$\tan\theta=\frac{-6.26}{12.244}$$

$$=-0.511\doteq-0.5$$

$$\log\left((c^2/f)\times\frac{10^{10}}{\delta}\right)=-0.5\log\frac{s}{r}+c'$$

$$c^2/f\times\frac{10^{10}}{\delta}=c''\left(\frac{s}{r}\right)^{-\frac{1}{2}}$$

$$c^2/\delta f=c''\sqrt{\frac{r}{s}}\,10^{-10}$$

$$\alpha=c^2/f_{..}=344\sqrt{\frac{r}{s}}\times10^{-10}$$

Digitized by Google

This gives:

$$a = 344\sqrt{\frac{r}{s}} \times 10^{-10}$$ per cm. of total cond. at 25 deg. cent. 76 cm. barometer

and this is the final value of the constant.

TABLE XVI

CALCULATION OF CURVE 32 FROM $(c^2/f) \times 10^{10} = 344\sqrt{\frac{r}{s}}$

$\frac{s}{r}$	$\sqrt{\frac{r}{s}}$	$\frac{c^2}{f} 10^{10}$
250	0.0633	21.84
500	0.0447	15.44
1000	0.0316	10.92
1500	0.0258	8.92
2000	0.0224	7.72
3000	0.0183	6.32
4000	0.0158	5.44
6000	0.0128	4.44

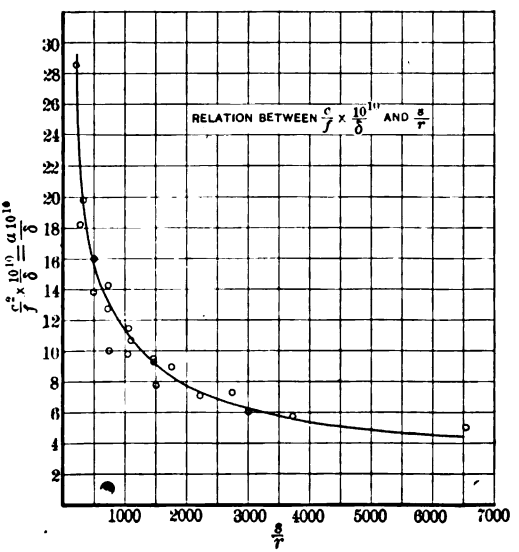


FIG. 32.—Corona loss

Curve 32 is plotted from the points calculated in Table XVI, while the circles show the actual experimental points.

Digitized by Google

Curve 33 shows a straight line relation between log s/r and log a. We may now write the equation for the power loss at 25 deg. cent. and 76 cm. barometric pressure:

$$p = 344\, f \sqrt{\frac{r}{s}} (e - e_0)^2\, 10^{-10}$$

where p = the energy loss per centimeter of total conductor in kilowatts.

e = kilovolts to neutral.

e_0 = disruptive critical kilovolts to neutral at 25 deg. cent. and 76 cm. barometric pressure.

f = the frequency in cycles per second.

r = the radius of the conductor in cm.

s = is the distance between conductor centers in cm.

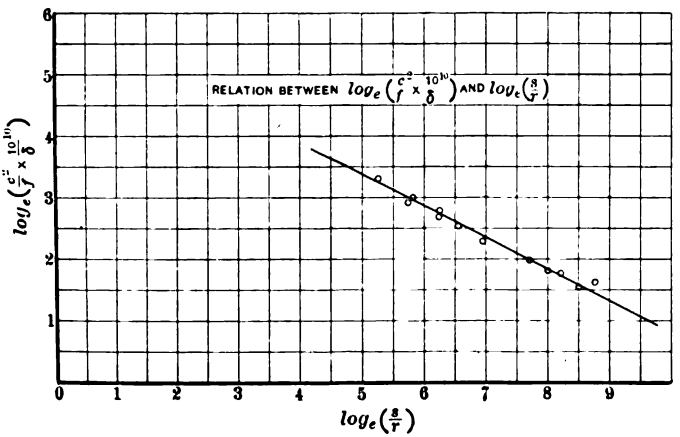


FIG. 33.—Corona loss

The value of e_0 varies with the radius of the conductor, r, and the spacing s, and will be discussed in section VI.

VI. THE DISRUPTIVE CRITICAL VOLTAGE

The point of greatest stress for a cylindrical conductor is at its surface. Where s/r is large the gradient at the surface of the conductor may be expressed:

$$g = \frac{de}{dx} = \frac{e}{r \log_e \frac{s}{r}}$$

where e = the voltage to neutral.

Digitized by Google

s = distance between conductor centers.

r = the radius.

Where r and s are in cm. and e is in kilovolts, g is expressed in kilovolts per cm. Now if e_0 the disruptive critical voltage is taken for e we have:

$$g_0 = \frac{e_0}{r \log_e \frac{s}{r}}$$

TABLE XVII.
DISRUPTIVE CRITICAL VOLTAGE GRADIENT FOR WIRES. VALUES CORRECTED TO 76 CM. BAROMETER AND 25 DEG. CENT.

Test No.	Spacing cm.	Diam. cm.	g. Kv/cm. max.	Per cent variation from mean	Per cent variation max. to min.
129	122	0.051	29.8		
133	183		29.8		
131	244		29.8		
130	366		29.8		
132	488		29.8		
			Avg = 29.8	—	—
91	152	0.168	31.3		
94	229		31.6		
92	410		29.1		
95	550		36.5		
			Avg = 30.9	5.8	7.9
134	122	0.328	28.8		
135	183		27.1		
136	244		29.0		
137	366		25.7		
138	488		25.3		
			Avg = 27.2	7.0	12.7
125	91.4	0.518	28.7		
126	183		26.5		
127	275		26.0		
128	397		26.2		
			Avg = 26.9	6.7	9.4
122	91.4	0.927	28.7		
123	183		30.4		
120	214		30.5		
124	275		31.0		
			Avg = 30.1	4.8	7.6
			Total Avg. 29.0		

Digitized by Google

TABLE XVIII

DISRUPTIVE CRITICAL VOLTAGE GRADIENT FOR CABLES. VALUES CORRECTED TO 76 CM. BAR. AND 25 DEG. CENT.

Test No.	Spacing cm.	Diam. cm.	g_0 Kv/cm. max.	Per cent variation from mean	Per cent variation max. to min.
73	91.4	0.585	26.5		
80	152		24.0		
79	244		23.9		
77	310		23.9		
82	432		25.0		
			Avg = 24.7	7.3	9.8
100	91.4	0.953	25.5		
115	91.4		26.2		
116	183		26.0		
117	275		26.4		
118	366		28.1		
			Avg = 26.4	6.4	9.3
			Line A 1-2-3-4		
18	310	1.181	25.5		
36	"		26.0		
37	"		25.3		
84	"		25.8		
101	"		26.5		
103	"		26.1		
104	"		25.7		
105	"		26.0		
109	"		25.8		
119	"		25.1		
119	"		26.0		
			Avg = 25.8	2.7	5.3
			Total Avg. 25.7	5.5	8.1

g_0 then is the stress at the conductor surface corresponding to e_0, and will be called the *disruptive gradient*, to distinguish it from the visual gradient g_v. Values of g_0 for wires and cables taken under a great variety of conditions are given in Tables XVII and XVIII. These values are corrected to standard temperature and pressure as explained in Section XI.

If we examine the values of e_0 for standard line A (1.8 cm. 7-strand cable) we find that the average value of g_0 is 25.8 kv. per cm. maximum. For cables between 0.583 cm. and 1.18 cm.

Digitized by Google

in diameter and various spacings, the average value of g_0 is 25.6 kv. per cm. maximum, or, in other words, g_0 *is constant for all sizes of cables, at all spacings, and is* 25.6 *kv.* per cm. maximum. In determining the value g_0 for seven-strand cables r was taken for convenience as the outside radius. Hence the above g_0 is not the *actual* g_0 as obtained for wires, but is an *apparent* g_0. The actual g_0 would be obtained by taking some mean radius r_2 between the outside radius r, and the radius to the point of contact of the outside strands r_1. r_2 approaches r in value as the number of strands are increased.

The values of g_0 for wires varying in diameter from 0.0508 cm. to 0.928 cm., and for spacings from 90 to 600 cm. are constant within the limits of experimental error. The mean value is:

$g_0 = 29$ kv. per cm. at 25 deg. cent and 76 cm. barometric pressure

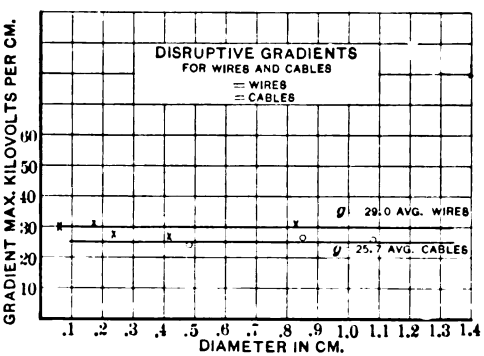


FIG. 34

Considerable variation should be expected in g_0 values due to:

1. Necessarily imperfect conductors, kinks, etc., in an outdoor line of this length.

2. Progressive change in the value of successive points on a given curve due to slight changes of wave shape, etc., as the voltage is increased, and the apparent shift of e_0.

The close agreement of g_0 for wires is for the above reasons remarkable.

Discrepancies due to progressive change are not to be expected for standard Line *A* to any great extent as the conductor spacing was always the same, and test conditions were kept as nearly constant as possible.

From the above then g_0 *is constant for all diameters of con-*

Digitized by Google

ductors and all spacings. This immediately suggests that g_0 is the actual rupturing gradient of air. More will be said of this in Section IX. Also:

$$\frac{g_0 \text{ cables}}{g_0 \text{ wires}} = m_0$$

where m_0 is a fraction which approaches unity as the irregularity of the surface is reduced, or number of strands increased, and is further discussed in Section X.

Then:

$$e_0 = \delta\, m_0\, g_0\, r \log_e \frac{s}{r} \tag{5}$$

(See curve Fig. 34).

The loss equation may now be written:

$$p = \frac{a}{\delta} f \sqrt{\frac{r}{s}} \left\{ e - \delta\, m\, g_0\, r \log_e \frac{s}{r} \right\}^2 \tag{6}$$

where p expresses the loss above the visual critical voltage e_v. The loss at the lower part of the curve will now be considered.

VII. Losses Near the Disruptive Critical Voltage $-e_0$

If the conductors could be made perfect no loss would occur below the visual critical voltage. However at low values of corona, two effects occur, which cause a deviation of the loss from the quadratic law, equation (1), and which affect the loss in opposite directions:

a. The loss of power does not begin at the voltage e_0, at which the disruptive gradient is reached at the conductor surface, but only after the disruptive strength of air has been exceeded over a finite and appreciable distance X from the conductor, that is, at a higher voltage e_r, as fully explained in Section VIII. See Fig. 39. Since the convergency of the lines of dielectric force is great at the surface of small conductors, with such conductors, a considerable increase of the voltage is required to extend the disruptive gradient to some distance from the conductor, and e_r is considerably higher than e_0, and thereby the decrease of loss below that given by equation (1) is appreciable with small conductors within the range between e_0 and e_v, as seen in Fig. 37,

Digitized by Google

With large conductors however, the lesser convergency of the lines of dielectric force at the conductor surface requires a lesser voltage increase beyond e_0, to extend the disruptive gradient to some distance from the conductor, e_0 and e_v are therefore closer together, and this decrease of the loss below the theoretical value given by equation (1) is not appreciable.

b. As the conductor surface can never be perfect, some loss of power occurs at and below the disruptive critical voltage at isolated points of the conductor, where irregularities of the surface, scratches, spots of mud or dirt, etc., give a higher potential gradient than that corresponding to the curvature of the conductor surface. With small conductors, this loss is rarely appreciable, since the curvature of the conductor surface is of the

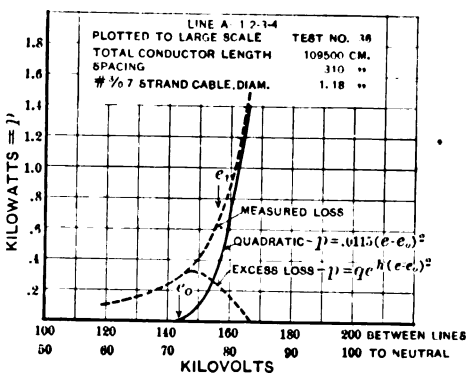


FIG. 35.—Corona loss near critical point

same magnitude as that of its irregularities. It becomes appreciable however for larger conductors, as seen in Fig. 35. This excess of the loss beyond that given by the quadratic law equation (1) essentially depends on the conductor surface, and is the larger, the rougher or dirtier the surface is. It is a maximum at the disruptive critical voltage e_0, and decreases above and below e_0, and is with fair accuracy represented by the probability curve:

$$p = q\,\epsilon^{-h(e_0 - e)^2} \qquad (4)$$

where q is a coefficient depending on the number of spots, and h is a coefficient depending upon the size of spots.

Snow, sleet and rain losses seem to be of the same nature, but frequently of far greater magnitude.

Digitized by Google

Equation (4) is probably of no practical importance as the loss is small, and q and h naturally cover a wide range of values depending upon the condition of the conductor surface. Experimental values near e_0 are taken from Table I and tabulated in Table XIX, together with values calculated by the quadratic

TABLE XIX

LINE A 1-2-3-4. FROM TABLE I. TEST 36. $\delta = 0.0115$ $e_0 = 72.1$

Kilovolts between conductors e'	Kw. exp. p_0	Kw. $p = 0.0115\,(e - e_0)^2$	Excess loss $p_1 = (p_0 - p)$	$\log_e p_1$	$(e_0 - e)^2$
120.4	0.11	——	0.11	2.40	146.5
130.2	0.15	——	0.15	2.71	49.0
139.2	0.22	——	0.22	3.09	6.2
150	0.40	0.10	0.30	3.40	8.5
159	0.79	0.63	0.16	2.77	54.7
165.8	1.42	1.34	0.08	2.10	11.7

law. Corresponding experimental and calculated values are subtracted and also tabulated.

Fig. 35 is plotted to a large scale to show the excess loss near e_0. This is for large conductors, e_0 and e_v are near together, and

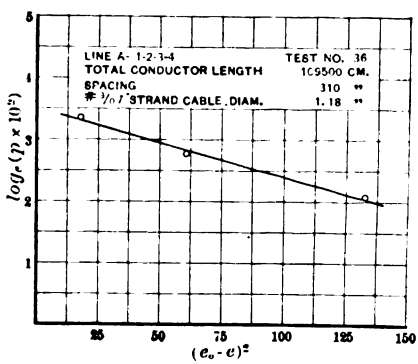


FIG. 36.—Corona loss method of reducing loss near critical point

the effect of (b) predominates. In order to see if equation (4) holds, write

$$\log_e p_1 = \log q - h\,(e_0 - e)^2$$

Then the curve between $\log p_1$ and $(e_0 - e)^2$ should be a straight line. This is shown in Fig. 36.

Digitized by Google

Values of q and h are of the following order for line A.

Test No.	q per cm. total conductor	h
30	3.19×10^{-6}	-0.0220
105	2.47 "	-0.0208
103	2.74 "	-0.0304

Fig. 37 is plotted from values for a small smooth conductor. Here e_0 and e_r are far apart, and as the curvature of the conductor surface is of the same magnitude as its irregularities they do not greatly influence the loss. The (a) effect here predominates—that is, the loss near e_0 is lower than that shown by the quadratic law.

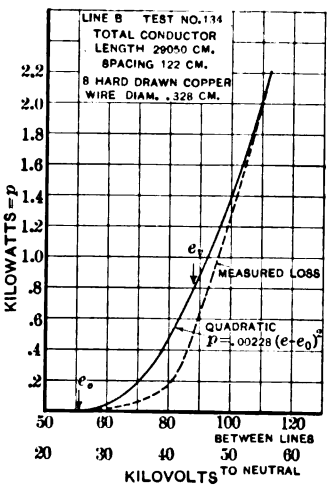


FIG. 37.—Corona loss near critical point

A phenomenon of the same nature as the above seems to occur in the striking distance between needle points. " Theoretically " the relation between volts and striking distance should be a straight line. This is practically so at high voltages, while at low voltages the curve deviates from the straight line. The voltage for small striking distances is higher than " theory " would warrant. This seems to be because a certain finite amount of energy must be stored in the dielectric about the point of discharge or, in other words, the voltage must be raised sufficiently above the " theoretical " voltage in order to extend the rupturing gradient over a finite distance. This is further discussed for visual corona on wires in Section VIII.

Digitized by Google

VIII. Visual Tests

Visual tests were made on two parallel conductors, supported indoors on a frame of treated wood. Wooden pins were used throughout the construction of this frame. The end supports were wooden wheels. This circular curvature prevented a flux concentration at the ends of the conductors. Two separate frames were used. One gave an active length per conductor of 308 cm., the other an active length of 610 cm. The distance above the floor was 150 cm. The maximum spacing between conductors was 107 cm.

The *visual critical point*, or point where visual corona starts is very definite for polished conductors, and can be repeatedly checked within a small per cent. The tests were made in a dark room and the method of procedure was as follows: Conductors of a given size were placed on the framework. Critical points were then taken at various spacings up to 107 cm.

The maximum intensity at the surface of one of two parallel conductors may be written:

$$\frac{d\,e}{d\,r} = g_r = \frac{e_r}{r \log_e \frac{s}{r}}$$

where e_r = the (maximum) voltage to neutral.
r = the radius of the conductor in centimeters.
s = the distance between the centers of conductors in centimeters.

This holds where s/r is large, or, when the flux is uniformly distributed at the surface of the conductors.

When s/r is small, that is, when the conductors are large and the spacing small, the flux is not uniform and g_r may be more closely approximated thus:

$$g_v = \frac{e\left(1+\frac{r}{\frac{s}{2}-r}\right)}{r \log_e \frac{s}{r}}$$

The following Table XX shows a typical set of readings. Note that g_r is *constant* for *all spacings*, for a *given size conductor*.

Digitized by Google

TABLE XX
VISUAL CRITICAL VOLTAGES
(g_v WITH VARYING SPACING AND CONSTANT DIAMETER)
POLISHED COPPER CONDUCTOR DIAMETER 0.0343 cm.

s cm.	ev' kilovolts between conductors (Effective)	ev' kilovolts between conductors (maximum)	g_v kv/cm (maximum)
2.54	12.1	17	99.5
2.93	12.4	17.4	99
3.18	12.5	17.7	98.5
3.81	13.0	18.4	99
4.45	13.5	19.0	99.5
5.08	13.8	19.4	100
5.73	14.0	19.8	99
7.62	14.5	20.5	99
15.2	16.0	22.6	97.2
30.5	17.7	25	97.2
45.6	18.7	26.3	96.1
61.0	19.4	27.4	98
106.8	20.6	29	97.2
			Average 99

Sets of readings similar to the above were taken on wires varying in diameter from 0.02 to 0.93 cm. The average values are tabulated in Table XXI.

Note that these values are taken for a number of different metals. The points all fall on the curve plotted between g_v and diameter. That is, the critical gradient is independent of the conductor material.

Now it seems reasonable to assume that air under constant conditions should break down at a constant potential gradient g. An examination of table XXI shows that g_v increases as the diameter of the conductor decreases. This is also shown on the curve Fig. 38. The apparent increase in the dielectric strength of air surrounding small conductors was explained by Steinmetz some years ago by the assumption of a condensed air film at the surface of the conductor. If this were so, a greater critical gradient would be expected for tungsten than for aluminum. That is, the air film should be denser around the denser metals. As already noted Table XXI and curve, Fig. 38, show that the gradient is not affected by the material or density of the conductor. In a paper read at the Annual Convention of the

Digitized by Google

A. I. E. E., June 1910* by Hayden and Steinmetz, it was shown that energy as well as voltage was necessary to rupture insulation. Also see Ryan's† explanation by the ionization theory. Applying this definite energy theory to corona formation, it means that the potential gradient at the surface of the conductor must be raised above the actual breakdown gradient in order to store

TABLE XXI

VARIATION OF g_v WITH DIAMETER OF CONDUCTORS (AVERAGE VALUES FOR POLISHED WIRE). CORRECTED TO 25 DEG. CENT 76 CM. BAROMETRIC PRESSURE

Diameter cm.	$\frac{de}{dr} = g_v$ kv/cm. max.	Material
0.0196	116	Tungsten
0.0343	99	Copper
0.0351	94	"
0.0508	84	Aluminum
0.0577	82	"
0.0635	81	Tungsten
0.0780	76	Copper
0.0813	74	"
0.1637	64	"
0.1660	64	Iron
0.2043	59	Copper
0.2560	57	Aluminum
0.3200	54	Copper
0.3230	50.5	"
0.5130	49	"
0.5180	46	"
0.6550	44	"
0.8260	42.5	"
0.9280	41	"

sufficient energy in the air immediately surrounding the conductor to cause breakdown at a distance x from the conductor surface. This distance x from the surface must be finite and the gradient at the point x a constant and equal to the dielectric strength of air g. See Fig. 39.

*A. I. E. E., June, 1910.
†A. I. E. E., January, 1911.

Digitized by Google

On the above assumptions we may write

$$g_v = \frac{e_v}{r\left(\log_e \frac{s}{r}\right)} = \text{visual gradient}$$

$$g = \frac{e_v}{(r+x)\log_e \frac{s}{r}} = \text{constant}$$

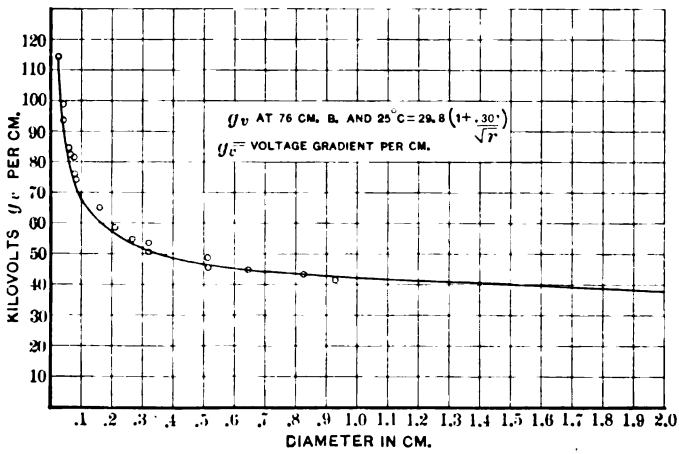


FIG. 38.—Visual critical voltage gradient—Two parallel wires

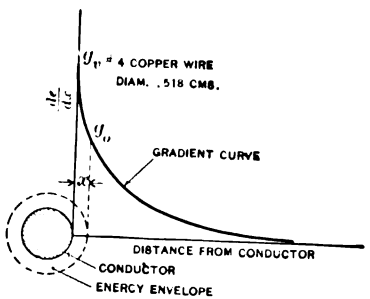


FIG. 39.—Potential gradient in air surrounding one of two parallel conductors

Now theoretically one is led to expect that x is not constant for all values of r, but:

$$x = \phi(r)$$

Then we may write:

$$g = \frac{e_v}{(r+\phi(r))\log_e \frac{s}{r}}$$

Digitized by Google

TABLE XXII

RELATION OF VISUAL CRITICAL VOLTAGE GRADIENT TO RADIUS(WIRES)
(EXPERIMENTAL VALUES)

CORRECTED TO 76 CM. BAROMETER AND 25 DEG. CENT.

Diam. cm.	g_v kv/cm.	Radius r = cm.	$\frac{1}{\sqrt{r}}$ cm.
0.0196	116.0	0.0098	10.10
0.0343	99.0	0.0172	7.65
0.0350	94.0	0.0175	7.58
0.0508	84.0	0.0254	6.27
0.0577	81.5	0.0288	5.90
0.0635	81.0	0.0317	5.64
0.078	76.0	0.0390	5.08
0.0813	73.5	0.0406	4.96
0.1635	63.8	0.0818	3.51
0.1660	63.4	0.0830	3.45
0.202	59.1	0.1010	3.13
0.257	56.7	0.128	2.76
0.320	54.3	0.160	2.51
0.322	49.6	0.161	2.51
0.513	48.8	0.256	2.01
0.518	44.5	0.259	1.94
0.655	43.7	0.327	1.82
0.826	42.2	0.413	1.57
0.928	40.6	0.464	1.44

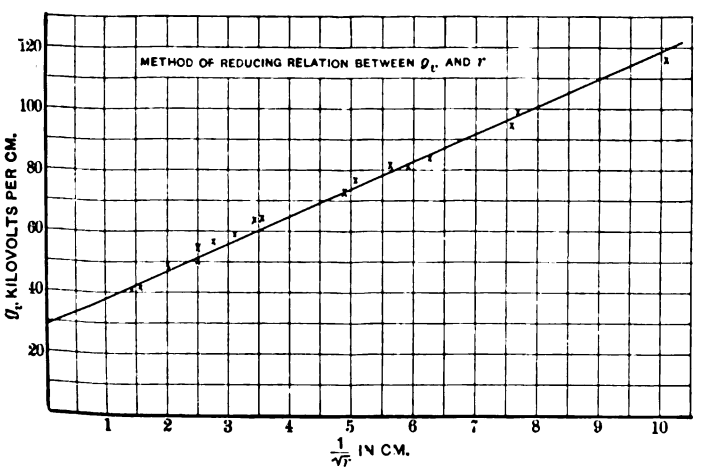


FIG. 40.—Visual Critical Voltage Gradient

Digitized by Google

A study of the experimental values show that if g_v is plotted with $1/\sqrt{r}$, the curve is a straight line. See Table XXII and Fig. 40. That is,

$$g_v = g\left(1+\frac{k}{\sqrt{r}}\right)$$

In order to give proper weight to all of the experimental points the $\Sigma\,\Delta$ method is used in the evaluation of the constants. See Table XXIII.

TABLE XXIII

RELATION OF g_v AND $\frac{1}{\sqrt{r}}$

($\Sigma\,\Delta$ reduction)

g_v	$\frac{1}{\sqrt{r}}$	g_v	$\frac{1}{\sqrt{r}}$
99	7.65	59	3.13
82	5.90	54	2.51
81	5.64	50.5	2.51
76	5.08	49	2.01
74	4.96	41	1.44
Σ 412	Σ 29.23	Σ 253.5	Σ 11.60

$\Delta\,\Sigma\, g_v = 158.5$ $\qquad$ $\Delta\,\Sigma\,\frac{1}{\sqrt{r}} = 17.63$

$\Sigma\,\Sigma\, g_v = 665.5$ $\qquad$ $\Sigma\,\Sigma\,\frac{1}{\sqrt{r}} = 40.83.$

$$c_1 = \frac{158.5}{17.63} = 9.00$$

$$g = \frac{665.5 - 9\times 40.8}{10} = 29.8$$

Therefore:

$$g_v = 29.8 + \frac{9}{\sqrt{r}}$$

$$= 29.8\left(1+\frac{0.301}{\sqrt{r}}\right)$$

These values give 29.8 kilovolts per cm. maximum as a rupturing gradient of air at 25 deg. cent. and 76 cm. barometer. We may find x thus:

$$\frac{g_v}{g} = \left(1+\frac{0.301}{\sqrt{r}}\right)$$

$$\frac{g_v}{g} = \frac{\frac{e_v}{r\,(\log s/r)}}{\frac{e_v}{(r+x)\,\log s/r}} = \frac{r+x}{r}$$

Digitized by Google

therefore

$$\frac{r+x}{r} = \left(1+\frac{0.301}{\sqrt{r}}\right)$$

$$x = 0.301\sqrt{r}$$

Fig. 41 is plotted from equation (6). The experimental points are shown as circles. Taking the correction factor given in section XI for barometric pressure and temperature we may now write:

$$g_v = 29.8\, m_v\, \delta \left(1+\frac{0.301}{\sqrt{r}}\right) \text{ kv. per cm. maximum}$$

$$= 21.1\, m_v\, \delta \left(1+\frac{0.301}{\sqrt{r}}\right) \text{ kv. per cm. effective}$$

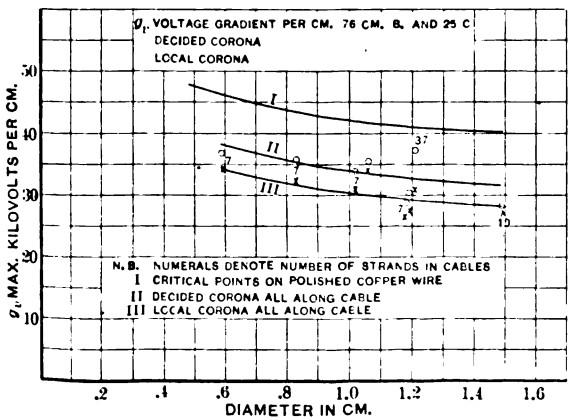


FIG. 41.—Visual Critical voltage gradient—Two parallel cables

Also

$$e_v = 21.1\, m_v\, \delta\, r \left(1+\frac{0.301}{\sqrt{r}}\right) \log_e \frac{s}{r} \text{ effective kv. to neutral} \quad (5)$$

The *numerical value of g determined above is practically the same as the numerical value of g_0 determined from the disruptive critical voltage.* The above values are for polished wires.

While the visual critical point is quite sharp and definite for wires it is not so for cables. This point for cables seems to come on gradually and cover a considerable range.

Table XXIV and Fig. 41 give average values for cables.

Digitized by Google

TABLE XXIV

VISUAL TESTS ON CABLES

Diam. cm.	strand	Decided corona			Local corona		
		g_v max. per cm.	g_v max. corr. per cm. 25° C. 76 cm.	Avg.	g_v max. per cm.	corr. 25° C. 76 cm.	Avg.
0.585	7	40.4	38.9		39.2	37.8	
0.585	7	39.3	36.2	37.1	36.5	33.7	35.3
0.585	7	38.4	36.3		36.1	34.3	
0.831	7	37.0	35.7	35.7	33.4	32.4	32.4
1.020	7	34.9	33.7	33.7	32.0	31.9	31.9
1.063	19	36.7	35.4	35.4	34.8	33.7	33.7
1.181	7	33.4	32.7		31.4	30.9	
1.181	7	24.3	23.0	28.9	21.5	20.4	26.9
1.181	7	28.2	27.0		25.4	24.4	
1.181	7	34.2	33.0		32.0	31.9	
1.193	19	30.6	30.1	30.1	28.2	27.7	27.7
1.209	37	37.2	36.4	36.4	35.8	35.1	35.1
1.485	19	28.7	28.3	28.3	28.0	27.6	27.6

The values for wires are plotted on the same sheet. There is nearly a constant difference between the two curves, that is, the visual critical gradient for cables g_v', equals the visual critical gradient for polished wires, g_v, times the constant m_v. Increasing the number of strands in a cable appears to increase the value of m_v.

Photographic Study. A photographic study of corona on wires and cables was made as follows: Two parallel conductors were spaced 122 cm. between centers. The camera was focused on one conductor only. The distance to the lens was such as to show the conductors at approximately actual size. An exposure was made for a given time at a given voltage. The plate was then shifted slightly, the voltage was raised, and an exposure made for the same time. That is, a given series shows the same part of the same single wire at different voltages. This operation was repeated until the series for a given wire was complete. See Fig. 42. These photographs are shown in Figs. 43–50.

Fig. 43 shows corona on a bright tinned phosphor bronze wire—0.051 cm. in diameter.

Fig. 44 shows corona on a bright copper wire (0.186 cm.) diameter—polished after each exposure.

Digitized by Google

Fig. 45 shows the same wire used in Fig. 44. But allowed to remain idle a few hours after running at 200 kv.

Fig. 46 shows a weathered (0.168 diameter) galvanized iron wire.

Fig. 47 shows a bright polished rod. and a new unpolished 3/0 copper cable.

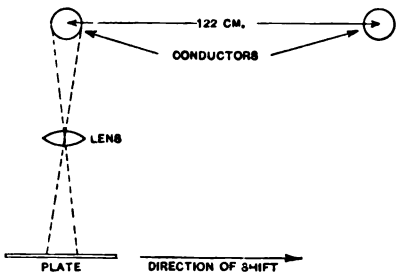


FIG. 42.—Method of making photographs of corona on short length conductors

These photographs explain much in the study of corona, for instance, variations in k, and g_0, the effect of moisture, loss at low voltage, etc. A complete discussion must be left to another paper. The conditions shown cover more than the practical range.

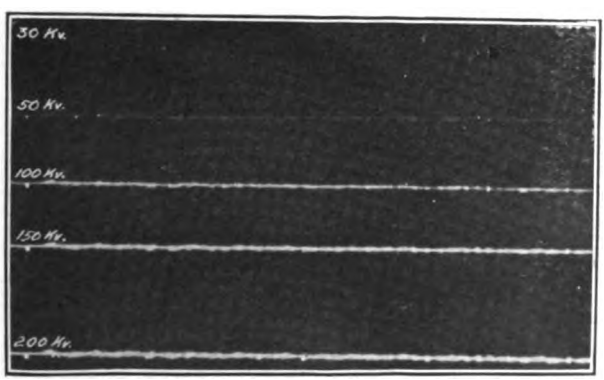


FIG. 43.—Phosphor bronze bright tinned wire. Diameter .051 cm.

IX. RELATION BETWEEN VISUAL CRITICAL VOLTAGE—AND DISRUPTIVE CRITICAL VOLTAGE

In Section VIII it was shown by loss measurements that for wires:

$$g_0 = \text{constant} = 29 \text{ kv. per cm. maximum}$$

Digitized by Google

By visual measurements in Section VIII it was shown that:

$$g_v = g\left(1 + \frac{0.301}{\sqrt{r}}\right)$$

where $g = 29.8$.

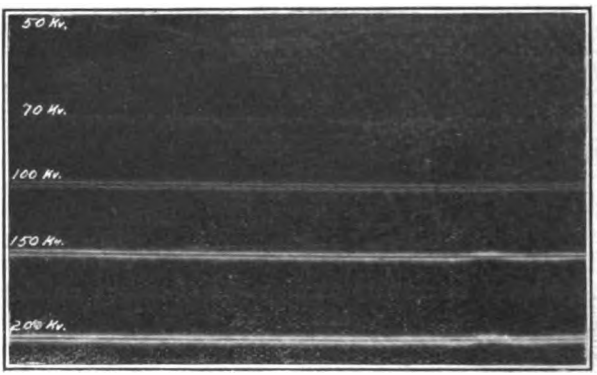


FIG. 44.—Polished copper wire. Diameter .186 cm. Polished after each exposure

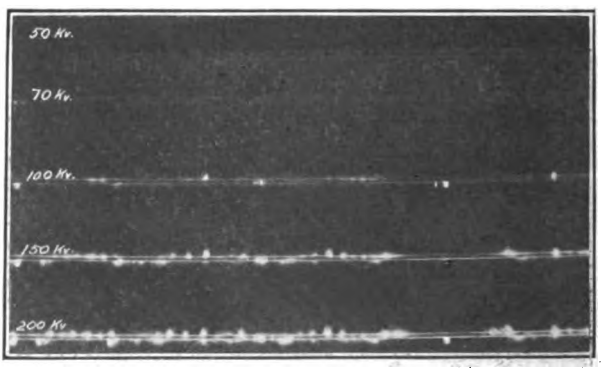


FIG. 45.—Polished copper Wire. 186 cm. Run at 200 kv. then allowed to stand idle. (this shows effect of oxidation)

Then where $r = \infty$, or for flat surfaces, $g_v = g = 29.8$.

The agreement between g as determined visually, and g_0 as determined by loss measurement is remarkable considering the different methods followed. It means that $g_0 = g = 29.8$ kv. *per cm. = dielectric strength of air at 25 deg. cent. and 76 cm.*

Digitized by Google

More weight is given to 29.8 as the value for the dielectric strength of air, as it was made on polished wire, and by a direct method. While g_0 was necessarily determined on long lengths of unpolished and more or less kinky wires by an indirect method. See Fig. 50.

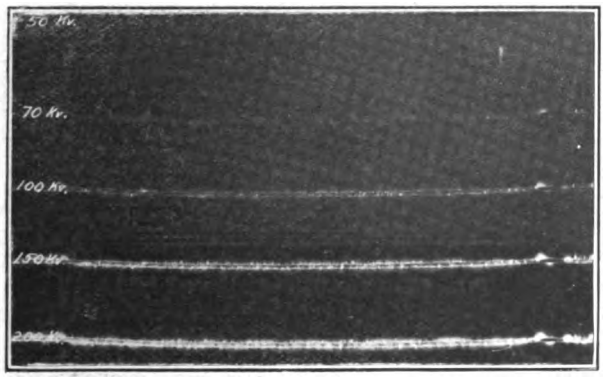


FIG. 46.—Weathered galvanized iron wire. Diameter 0.168 cm.

FIG. 47.—1.25-cm. polished brass rod and unpolished copper cable

X. IRREGULARITY FACTOR

Two factors effecting e_0 and the *apparent* g_0 have been used in equations and discussed. The numerical values covering the range of transmission practice are:

For wires:

$m_v = m_0 = 1$ polished wire.
$= 0.98$ to 0.93 } roughened or weathered wire.

Digitized by Google

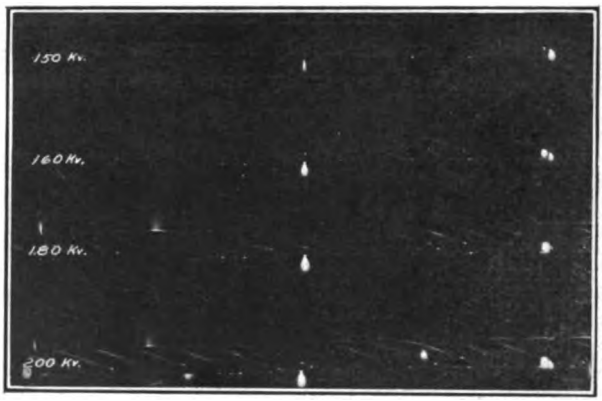


FIG. 48.—No. 3/0 weathered cable

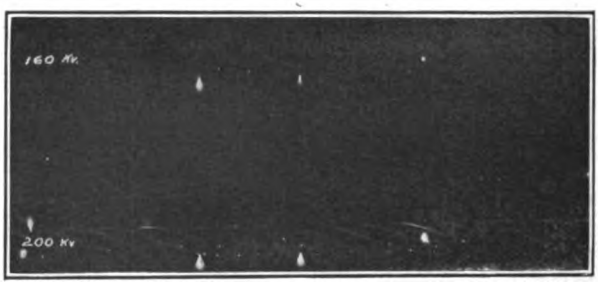


FIG. 49.—No 3/0 line cable—Dry

FIG. 50.—No. 3/0 line cable—Wet

Digitized by Google

For cables:

$$m_0 = 0.87 \text{ to } 0.83$$

$$m_v = 0.82 \text{ to } 0.72$$

k in equation (6) will vary somewhat with wave shape etc. But this variation can generally be neglected as it enters the equation directly, while the e_0 variation enters as the square. The value given should cover practical conditions.

XI. Temperature and Barometric Pressure

Values of the *disruptive critical voltage* e_0 covering a considerable temperature range are tabulated below. In Table XXV

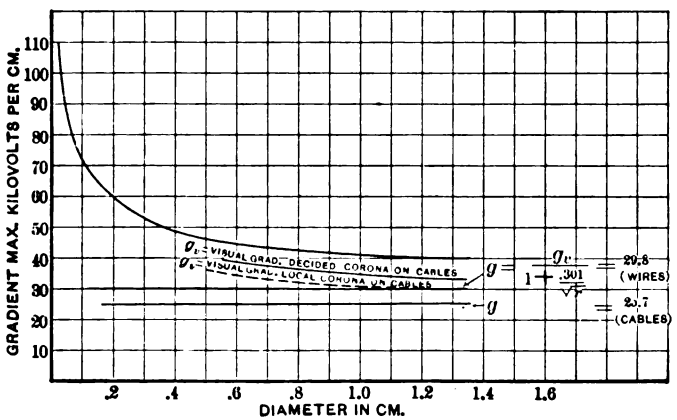


FIG. 51.—Visual and disruptive gradients for wires and cables

correction is made to a barometric pressure of 76 cm. on the assumption that e_0' varies directly with the pressure. In Fig. 52 $1/e_0'$ is plotted with temperature. The straight line through *these points cuts the temperature axis* at -273 deg. cent. or *absolute zero.* Temperature was always measured in the shade. The points that do not fall well on the curve are the summer sunny day points. This is what would be expected as the conductors were at a higher temperature than the temperature read.

Fig. 52 shows that the critical voltage or the rupturing gradient varies inversely as the air density.

The density of air at 25 deg. cent. and 76 cm. barometric pressure is used as the standard in this paper.

Digitized by Google

TABLE XXV
TEMPERATURE AND DISRUPTIVE CRITICAL VOLTAGE e_0
(Standard line *A* 1-2-3-4)

Test No.	Temperature		Bar cm.	e_0' kv. between lines	e_0' corr. to 76 cm.	$1/e_0'$	Weather
	Wet	Dry					
18	16	18.5	75.5	138.5	140	0.00715	Bright sun
15	20	22	75.2	140	142	0.00705	Cloudy sun
37	10	13	75.7	141	14	0.00705	Bright sun
36	10	12	75.0	144.2	146.5	0.00683	Cloudy
109	- 3	- 2	73.9	148.8	150.8	0.00663	Hazy sun
84	1	3	75.2	149	151	0.00662	Cloudy
101	- 1	- 1	74.7	153.8	156.8	0.00638	Cloudy
103	- 4.9	- 4.5	75.7	155.3	156.7	0.00638	Sun
104	- 9.5	- 9.5	76.2	157	157.0	0.00637	Sun
119	- 6.5	- 6	76.5	156.6	156.1	0.00642	Sun
105	-13	-13	76.2	161	161	0.00622	Sun

The factor for reducing the density of air, taken at a given standard temperature and pressure, to any desired temperature and pressure may be deduced as follows, and the factor which has been called δ in the previous discussion obtained.*

$$w = \frac{0.00465\, b}{273+t}$$

where w = the weight of air in grams per cubic cm.
b = barometric pressure in cm.
t = the temperature in degrees centigrade.

At 25 deg. cent. 76 cm.

$$w_{25°-76\text{ cm}} = \frac{0.00465 \times 76}{273+25} = 0.001185 \text{ grams}$$

w at desired temperature and pressure $w_{tb} = \dfrac{b}{273+t}$

$$\frac{w_{tb}}{w_{25°\text{ C}-76\text{ cm}}} = \frac{0.00465\, b}{(273+t)\ 0.001185} = \frac{3.92\, b}{(273+t)} = \delta$$

*This is the method used by Professor Ryan as the result of his laboratory experiments. The above table is a check on his work on a large scale.

Digitized by Google

where $(273+t)=T=$absolute temperature deg. cent.

$$\delta=\frac{3.92\,b}{273+t}=\text{correction factor.}$$

Then if e_0 increases directly with the air density

$$e_0''=\frac{3.92\,b}{273+t}\,e_0$$

where e_0 is the critical voltage at 25 deg. cent. and 76 cm. barometric pressure, and e_0'' is the critical voltage at the desired

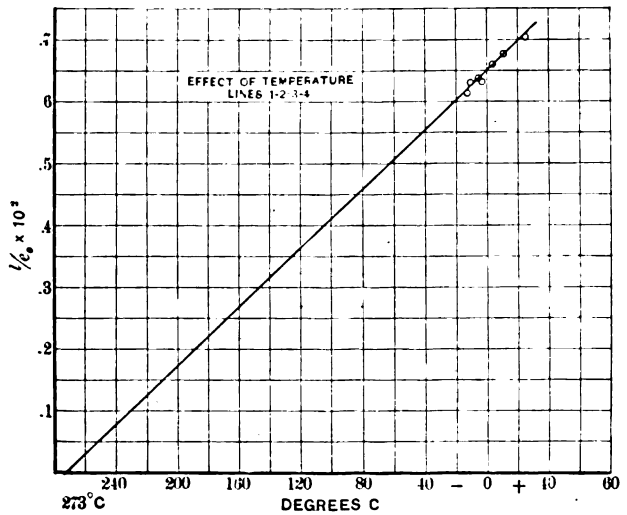


FIG. 52.—Corona loss

temperature pressure—of course the corresponding values of g_0 may be found the same way.

XII. HUMIDITY, SMOKE, WIND

Humidity. Line *A* was kept as a standard throughout the tests. A careful study of the disruptive critical voltage and c^2/f shows no effect of either humidity or "vapor products".* Visual tests made on two short parallel wires indoors and over a great humidity range also bear this out.

*High Voltage Measurements at Niagara. (Mershon), A. I. E. E., June 30, 1908.

Digitized by Google

TABLE XXVI
†STANDARD LINE A. CONDUCTORS 1-2-3-4

Test No.	Temperatures		Relative humidity	Vapor product	g_0 reduced to 25° C. 76 cm. bar.
	Wet	Dry			
15	20	22	0.84	0.55	18.8
18	16	18.5	0.75	0.35	18.5
36	10	12	0.78	0.25	18.8
37	10	13	0.67	0.21	18.3
84	1	3	0.69	0.11	18.7
101	- 1	- 1	1.00	0.17	19.2
103	- 4.9	- 4.9	1.00	0.13	18.9
104	- 9.5	- 9.5	1.00	0.08	18.6
105	-13	-13	1.00	0.06	18.8
109	- 2	- 2	1.00	0.12	18.7

Theoretically there should be no appreciable effect due to humidity, since even if the water vapor, which may be considered as a gas dissolved in air, has a different disruptive gradient than air, the percentage of the gas in the mixture should be too small to cause any appreciable change. It has been suggested that " vapor products " is a measure of ionization and, in that way, the critical voltage varies with vapor products. This does not seem likely, because with all ordinary atmospheric air the percentage of ionization is so small that it would not be expected to produce any effect. To test this, the visual critical point was determined on two parallel wires. The room was then closed and the wires were run at a point very much above the critical point for about an hour, or until a very intense odor of ozone filled the room. The voltage was then taken off and the surface of the wires cleaned in order to remove oxidization. The critical point was then redetermined and found to be the same, although the amount of ionized air was many times that which could be expected in free atmospheric air. Of course if the percentage of ionization is enough to change the constitution of the air, as for instance in an ozone machine, a change in the disruptive strength would then be expected.

It has been claimed that ultra-violet light reduces the sparking point. This is not borne out in tests, where any quantity of power is involved. Though ultra-violet light, ionized air,

†Line *A* was kept at constant test conditions for use as a standard in the study of varying atmospheric conditions, etc.

Digitized by Google

and various radiations, cause the small energy in condensers to discharge when applied over comparatively great time, in case of large energy discharge in a very short time, as spark discharge, and corona, no appreciable effect should be expected, or can be observed, since the discharge which takes place by ionized air is not of the same order of magnitude as the spark discharge.

The conditions are not the same with fog, here there is not a mixture of two gases, air and water vapor, as is the case where humidity is concerned, but actual water particles are in the air. It has been observed by Steinmetz that fog actually raises the striking distance between needle points. This is because the conducting water particles have the effect of increasing the size of the discharge points. With balls as electrodes, or where the electrodes are already large, fog would probably decrease the striking distance. Greater loss should be expected in corona measurements during fog due to charge and discharge of the water particles. This causes loss at lower voltages and has the effect of decreasing the critical point; it is more fully discussed in Section XIII.

Smoke. It was difficult to get measurements to show the effect of smoke, as the prevailing winds were from over the fields and towards the city. At one time, however, during a change in the wind thick smoke was blown over the line from rubbish dump and smoke stacks of a factory. The loss was increased. This however will probably not be a serious consideration in practice.

Wind. Losses measured during very heavy winds show no variation from losses measured during calm weather.

XIII. Moisture, Frost, Fog, Sleet, Rain and Snow

During some of the first tests it was noted that the losses were sometimes greater on the "going up curve", than on the "coming down curve", especially in the early mornings after heavy dew. The losses became less after the line had been run for a while at high voltage, Fig. 53 shows this well for a conductor with a coating of frost. This excess loss was thought at first to be due to leakage through moisture on the insulators. Insulators were put up without line wires, but measurements showed a very small insulation loss even during storms. It was then concluded to be due to moisture on the conductors themselves. Visual tests made on short lengths of wet and dry cables showed this in a very striking manner. Two parallel dry cables were

Digitized by Google

brought up to the critical point. Water was then thrown on the cables. What was a glow on the surface of the dry cables now became, at the wet spots, a discharge extending as much as 5 to 8 cm. from the cable surface. This discharge reminded one of an illuminated atomizer. Illustrations, Figs. 49 and 50 show this, but a great part of the effect is lost in reproduction. The wires became quite dry and down to normal discharge after running at high voltage for a very few minutes.

The curves, Fig. 54, taken during fog also show the combined effect of condensed moisture on the cables, and free water particles in the air. The moisture particles on the conductor become charged and are repelled. The particles in the air also

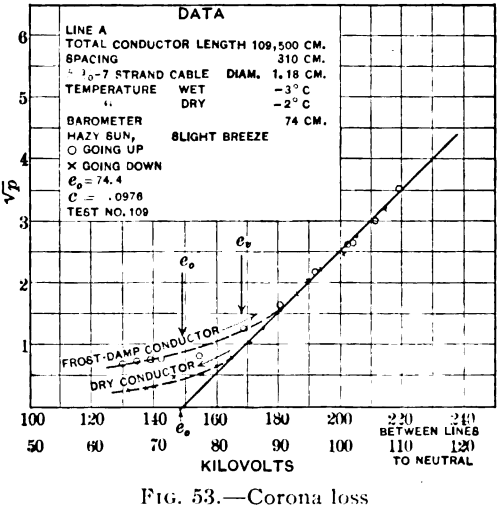


FIG. 53.—Corona loss

become charged and discharged thus increasing the loss very greatly above that for dry conductors.

The losses during snow and rain storms are much greater than fair weather losses at the same temperature and barometric pressure. In Fig. 56 the actual measured loss is plotted, and also a corresponding calculated fair weather loss. The difference between the two curves shows the excess loss due to snow. The effect of snow is greater than that of any other storm condition. This is because the particles are larger and a greater number strike the line, or come near the line.

The sleet curves are of special interest. Sleet had already started to form on the conductors, and was still falling when the

Digitized by Google

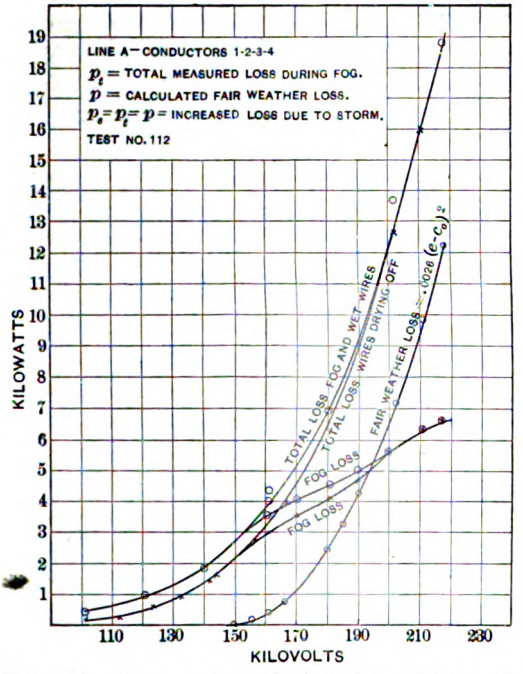

LINE A—CONDUCTORS 1-2-3-4
p_t = TOTAL MEASURED LOSS DURING FOG.
p = CALCULATED FAIR WEATHER LOSS.
$p_s = p_t - p$ = INCREASED LOSS DUE TO STORM.
TEST NO. 112
KILOWATTS
KILOVOLTS
TOTAL LOSS FOG AND WET WIRES
TOTAL LOSS WIRES DRYING OFF
FAIR WEATHER LOSS = .0028 $(e-e_0)^2$
FOG LOSS
FOG LOSS
FOG LOSS

FIG. 54.—Corona loss during fog. Wires wet

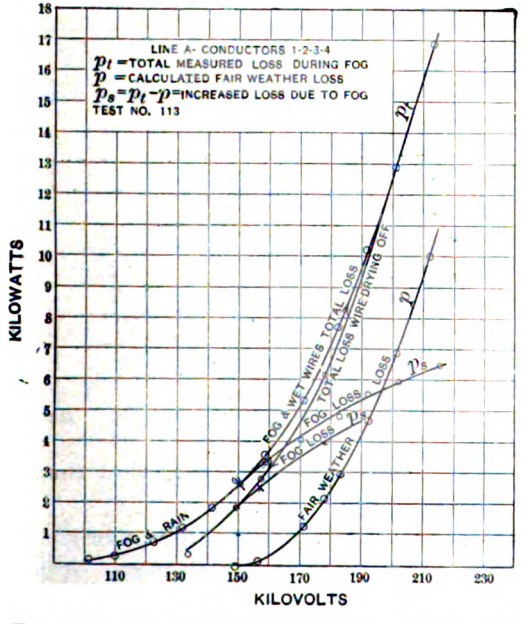


FIG. 55.—Corona loss during fog. Wires wet

Digitized by Google

tests were started. Fig. 57 shows the loss curves. After the curves were taken the line was kept at 200,000 volts for over an hour with no apparent diminution of sleet. This seems to show that sleet will form on high voltage transmission lines.

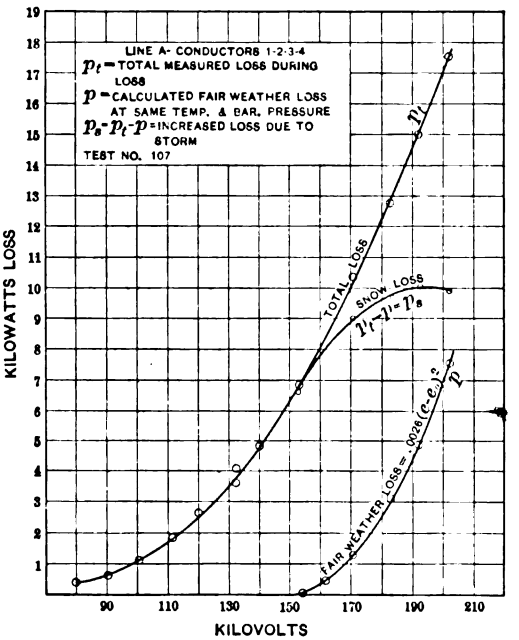

LINE A- CONDUCTORS 1-2-3-4
p_t = TOTAL MEASURED LOSS DURING LOSS
p = CALCULATED FAIR WEATHER LOSS AT SAME TEMP. & BAR. PRESSURE
$p_s = p_t - p$ = INCREASED LOSS DUE TO STORM
TEST NO. 107
KILOWATTS LOSS
KILOVOLTS
TOTAL LOSS
SNOW LOSS
$p_t - p = p_s$
FAIR WEATHER LOSS = .0028(e-e.)²

FIG. 56.—Corona loss during snow storm

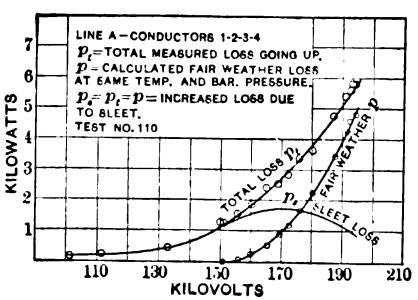

LINE A—CONDUCTORS 1-2-3-4
p_t = TOTAL MEASURED LOSS GOING UP.
p = CALCULATED FAIR WEATHER LOSS AT SAME TEMP. AND BAR. PRESSURE.
$p_s = p_t - p$ = INCREASED LOSS DUE TO SLEET.
TEST NO. 110
KILOWATTS
KILOVOLTS
TOTAL LOSS p_t
FAIR WEATHER p
SLEET LOSS p_s

FIG. 57.—Corona loss during sleet storm

The day after these tests were made was bright and clear and the conductors were still coated with sleet. A set of readings were taken, and it is interesting to note that the excess loss here is as great as when sleet was falling. See Figs. 58 and 59.

Digitized by Google

The excess loss for sleet, rain or snow storms (over the fair weather loss) seems with increasing voltage to approach a maximum and then to decrease again (the latter at values very far above the disruptive critical voltage), and the curves of loss seem

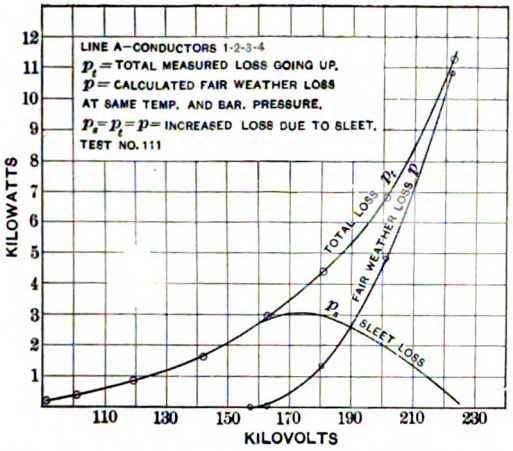

LINE A—CONDUCTORS 1-2-3-4
p_t = TOTAL MEASURED LOSS GOING UP.
p = CALCULATED FAIR WEATHER LOSS AT SAME TEMP. AND BAR. PRESSURE.
$p_s = p_t - p$ = INCREASED LOSS DUE TO SLEET.
TEST NO. 111
KILOWATTS
KILOVOLTS
TOTAL LOSS p_t
FAIR WEATHER LOSS p
p_s
SLEET LOSS

FIG. 58.—Corona loss—Wires coated with sleet

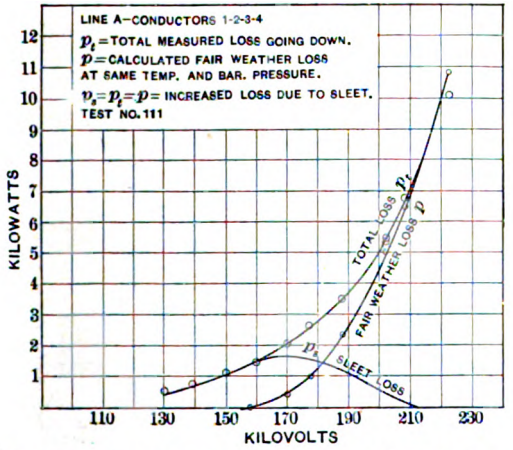

LINE A—CONDUCTORS 1-2-3-4
p_t = TOTAL MEASURED LOSS GOING DOWN.
p = CALCULATED FAIR WEATHER LOSS AT SAME TEMP. AND BAR. PRESSURE.
$p_s = p_t - p$ = INCREASED LOSS DUE TO SLEET.
TEST NO. 111
KILOWATTS
KILOVOLTS
TOTAL LOSS p_t
FAIR WEATHER LOSS p
p_s
SLEET LOSS

FIG. 59.—Corona loss—Wires coated with sleet

to have the general shape of the probability curve, as is to be expected theoretically.

The above readings show the importance of taking weather conditions into account in the design of high voltage transmission lines.

Digitized by Google

TABLE XXVII
CORONA LOSS. DURING FOG
(Data for Curves Fig. 54)

Kv. between lines e'	Amperes total	Kw. read total p_t	Fair weather loss calculated $p = a f (e - e_0)^2$	Kw. excess loss or snow loss $p_t - p = p_s$
101.0	0.109	0.41	——	0.41
121.0	0.130	0.93	——	0.93
140.0	0.156	1.81	——	1.81
161.2	0.185	4.25	0.36	3.89
180.0	0.214	6.94	2.42	4.52
202.0	0.257	13.66	7.15	6.51
202.0	0.252	13.07	7.15	5.92
202.0	0.252	12.77	7.15	5.62
218.0	0.288	18.79	12.20	6.59
211.0	0.272	16.02	9.85	6.17
202.0	0.250	12.77	7.15	5.62
190.0	0.229	9.21	4.27	4.94
185.0	0.217	7.63	3.28	4.35
180.0	0.215	6.60	2.42	4.18
180.0	0.200	4.95	2.42	2.53
166.0	0.189	3.99	0.71	3.66
156.0	0.177	2.82	0.11	2.71
144.0	0.160	1.65	——	1.65
142.0	0.159	1.45	——	1.45
132.5	0.146	0.97	——	0.97
123.7	0.131	0.62	——	0.62
112.5	0.119	0.26	——	0.26
102.5	0.110	0.15	——	0.15

Line *A*. 1-2-3-4. Test No. 112

Total conductor length..... 109,500 cm.
No. 3/0 7-strand cable diameter..... 1.18 cm.
Spacing..... 310 cm.
Temperature..... Wet 2 deg. cent.
Dry 2 deg. cent.
Barometer..... 75.5 cm.
e_0 fair weather..... 74.7

Digitized by Google

TABLE XXVIII

CORONA LOSS. DURING FOG

(Data for curves Fig. 55)

Kv. between lines e'	Amperes total	Kw. read total p_t	Fair weather loss calculated $p = a f (e - e_0)^2$	Kw. excess loss or snow loss $p_t - p = p_s$
101.5	0.103	0.16	——	0.16
110.0	0.117	0.27	——	0.27
121.5	0.129	0.64	——	0.64
131.5	0.145	1.12	——	1.12
141.5	0.157	1.85	——	1.85
150.0	0.170	2.73	——	2.73
159.6	0.182	3.61	0.26	3.35
171.0	0.196	5.31	1.21	4.10
183.0	0.219	7.74	2.92	4.82
192.0	0.232	10.21	4.68	5.53
201.0	0.247	12.87	6.90	5.97
213.0	0.272	16.92	10.50	6.42
201.0	0.247	12.87	6.92	5.97
178.0	0.207	6.16	2.11	4.05
157.0	0.177	2.81	0.15	2.65
134.0	0.150	0.38	——	0.38

Line A. 1-2-3-4. Test No. 113

Total conductor length..... 109,500 cm.
No. 3/0 7-strand cable diameter..... 1.18 cm.
Spacing..... 310 cm.
Temperature..... Wet 2 deg. cent.
Dry 2 deg. cent.
Barometer..... 75.5 cm.
e_0 fair weather..... 74.7

Digitized by Google

TABLE XXIX

CORONA LOSS. DURING SNOW STORM

POINTS TAKEN GOING UP ON LINES 1-2-3-4

(Data for curves Fig. 56)

Kv. between lines e'	Amperes	Kw. read total p_t	Fair weather loss calculated $p = a f (e - e_0)^2$	Kw. excess loss or snow loss $p_t - p = p_s$
80		0.38	——	0.38
90.5		0.62	——	0.62
100.5		1.09	——	1.09
111.5		1.88	——	1.88
120.5		2.63	——	2.63
132.5		4.08	——	4.08
132.5		3.68	——	3.68
140.5		4.86	——	4.86
153.0		6.83	0.06	6.77
161.4		7.46	0.46	7.00
170.4		10.28	1.28	9.00
182.8		12.75	3.11	9.64
192.0		15.02	4.98	10.06
202.0		17.46	7.53	9.93

Line *A*. 1-2-3-4. Test No. 107

Total conductor length..... 109,500 cm.
No. 3/0 7-strand cable diameter..... 1.18 cm.
Spacing..... 310 cm. c
Temperature..... Wet −0 deg. cent.
Dry −0 deg. cent.
Barometer..... 74.2 cm.
e_0 fair weather..... 74.1

Digitized by Google

TABLE XXX

CORONA LOSS. DURING SLEET STORM

POINTS TAKEN GOING UP ON LINES 1-2-3-4

(Data for curves Fig. 57)

Kv. between lines e'	Amperes	Kw. read total p_t	Fair weather loss calculated $p = a f (e - e_0)^2$	Kw. excess loss or snow loss $p_t - p = p_s$
111.3		0.21	——	0.21
150.0		1.25	——	1.25
160.0		1.81	0.21	1.60
169.0		2.51	0.83	1.68
180.6		3.58	2.26	1.32
191.6		5.35	4.26	1.09
102.0		0.13	——	0.13
133.0		0.48	——	0.48
151.0		1.25	——	1.25
172.4		2.80	1.18	1.62
192.9		5.75	4.52	1.23
194.0		5.74	4.78	0.96
192.8		5.54	4.52	1.02
187.6		4.76	3.46	1.30
176.6		3.34	1.69	1.65
165.0		2.40	0.50	1.90
156.0		1.59	0.06	1.53
194.0		5.74	4.78	0.96
194.0		5.74	4.78	0.96

Line *A*. 1-2-3-4. Test No. 110

Total conductor length..... 109,500 cm.
No. 3/0 7-strand cable diameter..... 1.18 cm.
Spacing..... 310 cm.
Temperature..... Wet −1 deg. cent.
Dry −1 deg. cent.
Barometer..... 75.4 cm.
e_0 fair weather..... 75.6.

Digitized by Google

TABLE XXXI

CORONA LOSS

WITH SLEET ON WIRES. BRIGHT SUNNY DAY. POINTS TAKEN ON LINES 1-2-3-4

(Data for curves Figs. 58 and 59)

Going down

Kv. between lines e'	Amperes	Kw. read total p_t	Fair weather loss calculated $p = a f (e - e_0)^2$	Kw. excess loss or snow loss $p_t - p = p_s$
202.0		5.46	5.10	0.36
222.4		10.10	10.87	−0.77
208.0		6.74	6.58	0.66
2 .0		5.38	5.10	0.28
188.0		3.55	2.39	0.16
177.6		2.67	1.03	1.64
170.0		2.07	0.41	1.66
160.0		1.47	0.02	1.45
150.0		1.10	——	1 10
139.0		0.71	——	0.71
130.0		0.52	——	0.52
		Going up		
60.0		0.03	——	0.03
70.0		0.07	——	0.07
80.5		0.13	——	0.13
91.4		0.23	——	0.23
101.0		0.40	——	0.40
119.3		0.83	——	0.83
142.5		1.66	——	1.66
162.6		2.94	0.06	2.88
180.8		4.41	1.38	3.03
201.0		6.81	4.87	1.94
222.4		11.29	10.87	0.42

Line *A*. 1-2-3-4. Test No. 111

Total conductor length..... 109,500 cm.
No. 3/0 7-strand cable diameter..... 1.18 cm.
Spacing..... 310 cm.
Temperature..... Wet −10 deg. cent.
Dry −10 deg. cent.
Barometer..... 76 cm.
e_0 fair weather..... 78.8

Digitized by Google

XIV. Remarks

There is still much left for further discussion, and many speculations to put forth, but which for lack of time, must be left to a future and more theoretical paper. Under this heading may be mentioned:

Rationalization of equations.

*Energy storage at the conductor surface through the distance x before the visual point is reached.

*Further relations between capacity and a in equation (2) and value of a for very small conductors.

The extension of corona from the conductor surface and the resulting increase in capacity.

A further discussion of the quadratic law, and the losses at low voltages.

Storm losses.

Photographic study.

Unexplained corona phenomena.

*Work on rationalization of x and a seems to show that the values given are the first terms of a series.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

AUTOMATIC MOTOR CONTROL FOR DIRECT CURRENT MOTORS

BY ARTHUR C. EASTWOOD

"The flexibility of the electric motor" is a well worn phrase and one which is quite commonly accepted at its face value. As a matter of fact an electric motor has quite definite characteristics, and these characteristics usually must be modified by some form of controller to adapt a given motor to various conditions.

At the present time there is probably no branch of industry in which a machine is used which has not been invaded by the electric motor. This general use of electric motors carries with it the fact that these motors are daily started and controlled by al classes of operators, from the most highly skilled to the most ignorant and careless.

Where a manually operated starter is used, the rapidity with which the starting resistance is cut out, and hence the accelerating current, is left to the judgment of the operator. If the operator be ignorant or careless, damage to the motor and to the driven machine may result from cutting out the starting resistance too rapidly. On the other hand, if he is over-cautious he may consume more than the necessary period in cutting out the starting resistance, causing a waste of time, and possibly also a burned out rheostat. Or, if an operator be transferred from a machine which has small inertia and starts easily to a machine or tool which has great inertia (such as a punch press having a heavy flywheel), if he has not been previously instructed in the starting of the heavy machine, this part of his education may prove expensive to his employer.

Where motors are to be reversed as well as simply started,

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

the possibility of damage to the motor and driven machinery, due to careless manipulation of the controller, is much greater than is the case in simple starting because, if the motor connections be suddenly reversed while the motor is running, the counter e.m.f. of the armature becomes additive to the line voltage until such time as the armature has been brought to rest. In the case of series wound motors running under light load or of shunt wound motors running with weakened field, the voltage impressed on the armature and the starting resistance may readily be several times the normal line voltage. Destructive currents may therefore occur if the resistance is cut out too rapidly in the reverse direction.

Obviously the ideal arrangement for starting or reversing a motor is a starter or controller which will " do the thinking for the operator ", leaving it to him to simply push a lever to start the motor and pull the lever to stop the motor.

In the case of any motor-driven machine or tool there is a maximum safe accelerating current which should not be exceeded. This maximum safe current may be determined by the ability of the motor to commutate properly, or it may be determined by other conditions such as the slipping point of belts in a belt drive.

The ideal starter or controller should be so arranged that this maximum safe current cannot be exceeded. It should also be so arranged, in the interests of efficiency both as to current and to time, that the current during acceleration will be kept as closely as practicable up to the safe maximum value. In other words, the starter must automatically interpret load conditions. If the load be light the starter must see to it that the motor is brought up to speed quickly, while if the load be heavy, the period of acceleration must be correspondingly longer.

In the past there have been several types of starters and controllers which have approximated the characteristics above detailed. First may be mentioned the " time element " type in which the starting resistance is always cut out in a fixed period of time. This type of starter falls short of the ideal in that it cannot adapt itself automatically to variation in load.

Second, the " counter e.m.f. " type in which the starting resistance is cut out by a magnet or magnets which respond to the counter e.m.f. of the motor. This type of starter or controller has done good work in elevator service but is open to the objection that its action is disturbed by fluctuation in line voltage.

Digitized by Google

Third, the "current limit" type in which the cutting out of the starting resistance is governed by the motor current. This type is generally characterized by a number of shunt-wound magnetically-operated switches which control the starting resistance and one or more series relays which respond to the motor current and serve to check the successive closure of the resistance switches when the accelerating current exceeds a predetermined maximum. This type, which I will call the "shunt current limit type" in order to distinguish it from another type o be later considered, approaches the ideal very closely and has been the direct means of introducing the electric motor in many applications where steam and hydraulic power had been the previous standard.

A specific instance in point is found in the introduction of the motor drive for "reversing mill tables" in steel mills. These tables are reversed several thousand times a day, and up to less than ten years ago small steam engines were universally used to drive them. It had been attempted to use motors for the purpose, but with manually operated controllers and operators accustomed to operate hydraulic or steam valves both the motors and the machinery were so severely punished by excessive currents, due to cutting out the starting resistance too rapidly at the time of reversal, that the arrangement was operative, in a practical sense, only in the hands of a skilled and careful operator, and was too delicate to be used as standard equipment in a steel mill. The advent of the automatic magnetic controller, which automatically keeps the acceleration current within fixed limits, overcame the difficulty. With this type of control the master controller can be operated as rapidly and roughly as a hydraulic valve with no danger to the motor or the driven machine. No particular skill is required of the operator in starting or reversing the motor. It is left to him to simply push a lever to start the motor and pull a lever to reverse the motor. He is therefore free to devote all of his attention and skill to the business of working steel. He is no longer a combined motorman and steel-worker but a steel-worker pure and simple.

In addition to this advantage of the automatic controller, in that it eliminates the necessity for skill on the part of its operator, it carried with it other advantages having a direct bearing on increase in output. Among these advantages may be mentioned the following:

1. The master-controller is small and easily operated. The

Digitized by Google

physical endurance of the operator is eliminated as a factor in the output of the mill.

2. By keeping the accelerating current as nearly as practicable up to a safe maximum the motor is always brought up to speed in minimum time.

3. By keeping the current at the instant of reversal within safe limits delays due to both electrical and mechanical breakdowns are greatly reduced.

With these very practical advantages demonstrated, the electric motor with automatic control was very promptly adopted for the drive of mill tables, and is now the accepted standard in steel mills for this and many other drives.

The *shunt type of current limit controller* accomplishes the results for which it is intended in a thoroughly practical and satisfactor manner, but its general use is precluded at the present time by the fact that it is a highly organized piece of apparatus which is too complicated to be readily understood by an ordinary electrician. In other words, while the shunt type of current limit controller eliminates skill on the part of its operator, it requires a somewhat skilled electrician for its proper maintenance.

Some recent developments in automatic motor control of the current limit type which result in a very material simplification of the controller are described below. This new type of automatic controller or starter is known as the *series current limit type* in view of the fact that the magnetic switches which control the acceleration are series wound and their windings are connected in series with the motor to be started or controlled.

This type of controller is made possible by a type of magnetically-operated switch which possesses remarkable characteristics.

This switch acts not only as a switch for closing a circuit and holding it closed, but acts also as a current limit relay or so-called " throttle ". If the current which flows through the winding of the switch is below a certain critical value the switch will close instantly, while if the current is above this critical value the switch will " lock out " or refuse to close till the current has been reduced to the critical value. Means are provided whereby the critical value of current below which the switch will close and above which the switch will lock out may be readily adjusted, thereby adjusting the accelerating current taken by the motor.

Digitized by Google

Fig. 1 is a cross-sectional view of a typical switch of this type. In this illustration I is the operating coil, which as previously mentioned is so wound as to adapt it for connection in series with the motor to be controlled. This winding is carried by a brass tube within which the core E is free to reciprocate vertically. The upper end of the core E carries a non-magnetic stud to which is attached a copper contact plate G, adapted to make contact with a pair of contact brushes H when the switch

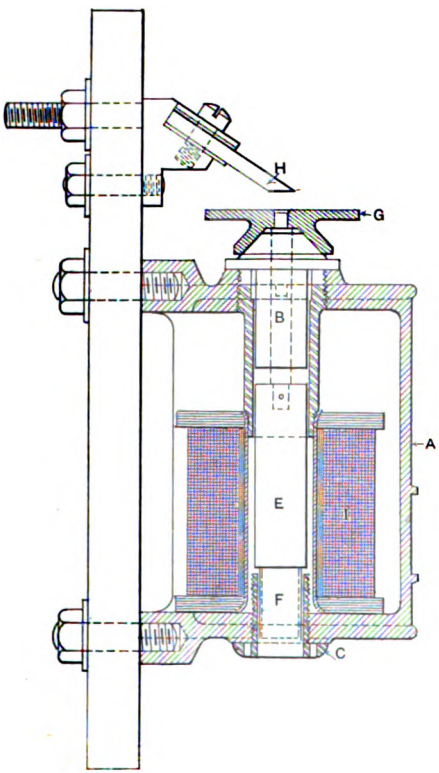


FIG. 1

is closed. The lower end of the core E is reduced in cross-section and forms a stem F which meets the body of the core to form a shoulder. The stem F passes into a hollow adjustable plug C which is of magnetic material. The winding of the switch is enclosed and protected by a semi-cylindrical iron casing A which also constitutes the return member of the magnetic circuit. The upper member of the frame or case A is provided

Digitized by Google

with a plug or pole piece B of magnetic material. When current flows through the winding I magnetic flux passes between the plug B and the upper face of the core E. Substantially all of this flux is normal to the face of the core E and is effective in producing a magnetic pull tending to close the switch. At the lower end of the core, however, the flux has two paths. One of these paths is from the horizontal portion of the frame A into the sleeve or hollow plug C, and from the upper face of this sleeve through an air gap into the shoulder on the core. This portion of the flux takes a direction practically normal to the face of the shoulder on the core and produces a magnetic pull which tends to move the core downward or, in other words, tends to prevent actuation of the switch. Through the second path at the lower end of the core a portion of the flux passes directly into the stem or extension F in a direction at right angles to the direction of motion, and this portion of the flux is therefore not effective in producing a pull on the core E in a vertical direction. The total flux divides between those two paths inversely as their reluctance. With a small current in the winding I substantially all of the flux passes directly into the extension F, this path being of much less reluctance than the path including the air gap. The extension F, however, is of restricted cross section and as the magnetic force is increased the reluctance of this path increases and more and more of the flux is crowded into the air gap.

The core E is then acted upon by two forces—one the magnetic pull at its upper end which tends to close the switch, and the other made up of the weight of the moving parts plus the downward magnetic pull at the shoulder on the plunger. When the current is below a certain critical value the upward pull is greater than the downward pull plus the weight of the moving parts and the switch will close. When the current is above this critical value the downward pull plus the weight of the moving parts predominates and the switch cannot close.

The critical point below which the switch will close and above which it will " lock-out " is adjusted by screwing the adjustable plug C in or out which adjusts the lower air gap. This has the effect of altering the reluctance in the path including the air gap with respect to the reluctance of the path including the stem or extension F. Screwing in the plug and thereby shortening the air gap has the effect of decreasing the value of current at which the switch will " lock-out ", while increasing the air gap

Digitized by Google

has the effect of increasing the value of current at which the switch will "lock-out".

Fig. 2 is a reproduction of the operating curves of one of these switches. The ordinates of these curves read in amperes and the abscissæ in fractions of an inch, showing the length of the lower air gap.

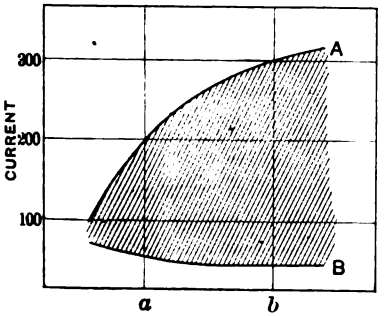


FIG. 2

The upper curve *A* is the "lock-out" curve, and the lower curve *B* shows minimum current at which the switch will close. The switch will close at any value of current between the two curves as measured on an ordinate corresponding to the length of air gap under consideration.

It will be observed that the curve *B* is a substantially horizontal line which shows that the minimum current at which the switch will close is very little affected by altering the lower air gap. The form and general pitch of the operating curve *B* are matters

FIG. 3

FIG. 4

of design into which the diameter of the stem or extension at the lower end of the core relative to the diameter of the core at its upper end and also the location of the magnetizing winding relative to the two air gaps in the magnetic circuit enter as important factors.

Digitized by Google

After the switch has closed it is held closed through a substantially closed magnetic circuit and it will therefore be held closed till the current in its winding has fallen almost to zero. Since both the winding of the switch and also its contacts are in the controlled circuit and the switch will not open till the current has fallen to practically zero, it follows that there can be no arcing at the switch contacts, and hence blow-outs or other arc-rupturing devices are not required.

Figs. 3 and 4 illustrate a complete unit switch of this type in side and front elevation. Starting with this unit switch as a basis, the switch being both a switch and a current-limit relay combined in one mechanism, we will consider some typical combinations of these switches in the form of automatic starters and controllers for performing various functions.

Fig. 5 is a diagram of connections of a simple form of automatic motor starter in connection with a compound wound motor having the armature A, series field F and shunt field f. K is the starting switch which is closed by the operator to start the motor and is opened to stop the motor, this being the only part of the starter with which the operator has anything to do. $S1$, $S2$, and $S3$ are three automatic switches which control the starting resistance R. These switches are provided with series-wound actuating coils $C1$, $C2$ and $C3$ respectively. The switch $S3$ is also provided with a shunt-wound holding coil $H3$.

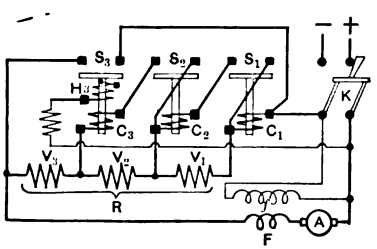


FIG. 5

When the starting switch K is closed current flows from the positive side of the switch through the armature and series field of the motor, the entire starting resistance R and the actuating winding $C1$ of switch $S1$ to the negative side of switch K. The motor should then start, and although the actuating winding of switch $S1$ is energized this switch will not close till the current has dropped to the value for which the switch is adjusted.

When switch $S1$ closes the first section of resistance $V1$ is short-circuited, the path of the current then being from the switch K through the armature and series field of the motor, the resistance sections $V3$ and $V2$, the winding $C2$ of switch $S2$, the contacts of switch $S1$ and the winding $C1$ of switch $S1$

Digitized by Google

to the switch K. The winding $C2$ of switch $S2$ is then energized and when the motor current has dropped to the value determined by the adjustment of the switch it will close, thus short-circuiting the section of resistance $V2$. The current then takes the following path: from the switch K through the armature and field of the motor, the resistance section $V3$, actuating winding $C3$ of switch $S3$, contacts and winding of switch $S2$, and contacts and winding of switch $S1$ to the switch K.

The actuating winding $C3$ of the last accelerating switch is thus energized and when the motor current has dropped to the predetermined accelerating value the switch $S3$ will close. As switch $S3$ closes the circuit through its shunt-wound holding coil $H3$ is completed at the contacts of the switch itself and the switch is held closed by this coil. The closure of switch $S3$ throws the motor across the line through the following path: from the positive side of switch K, through the armature and series field of the motor and the contacts of switch $S3$ to the negative line at switch K. The contacts of switch $S3$ are therefore the only contacts or connections in the motor circuit when the motor is running.

It will be observed also that closure of switch $S3$ short-circuits all three of the actuating coils $C1$, $C2$, and $C3$. Switches $S1$ and $S2$ therefore drop out, while switch $S3$ is held closed by its holding coil $H3$. It is also to be noted that switch $S1$ in closing closes the circuit through the actuating winding of switch $S2$, while switch $S2$ closes the circuit through the actuating winding of switch $S3$. The switches are thus compelled to close in orderly sequence without recourse to auxiliary or "interlock" contacts.

To stop the motor it is merely necessary to open the switch K. In case of failure of voltage the holding coil of switch $S3$ is de-energized and this switch opens, inserting all of the starting resistance R in series with the motor. When current is restored to the line (provided the operator has not previously opened the switch K) the motor will again be started automatically in the normal way. While Fig. 5 shows the connections for a compound-wound motor, it is evident that the same form of starter is equally applicable to shunt and series-wound motors. In the case of series-wound motors connected to loads which may be so reduced as to cause the motor to speed up dangerously, the starter can be very simply modified to protect against this. To accomplish this the holding coil of switch $S3$ is made a series coil and is connected in series with the contacts of the switch.

Digitized by Google

Since in a series motor the speed depends upon the current, the holding power of the holding coil will be weakened as the motor speeds up, and the coil may readily be proportioned so as to cause the switch $S3$ to open before a dangerous speed is reached.

A complete starter corresponding to the diagram of Fig. 5 is shown in Fig. 6.

As previously mentioned, there is no danger of arcing at the contacts of the accelerating switches, the motor circuit being initially closed and finally opened at the contacts of the operator's switch K. In the case of constantly running shunt or compound wound motors, a simple knife switch or its equivalent is suitable for the purpose where remote control is not a consideration. In applications where short moves of a heavy machine may be made, as, for instance, in setting up the work

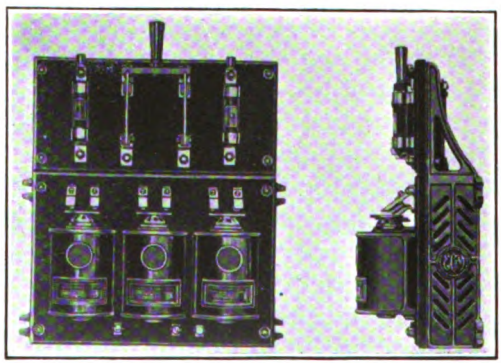


FIG. 6

on a boring mill, provision must be made for the arcing at the operator's switch due to opening the motor circuit when the motor is generating but a small counter e.m.f. This can be taken care of by providing a specially constructed operator's switch having its contacts suitably protected against arcing, or preferably a type of starter illustrated in Figs. 10 and 11 is employed.

In this form, in addition to the series-wound accelerating switches, a main switch or initial circuit-closer in the form of a shunt-wound magnetically operated switch or "contactor" is provided. This contactor provides for a quick opening of the circuit in the field of a powerful blow-out magnet such that heavy currents in an inductive circuit are opened promptly and with slight depreciation of contacts.

Digitized by Google

The use of this shunt-wound main switch makes it possible to use push-buttons or small pilot switches which are used by the operator in starting or stopping the motor. As many of

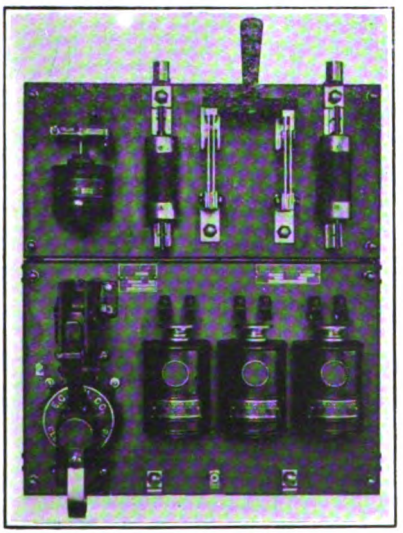


FIG. 7

these starting and stopping switches as desired may be placed at convenient points around a large machine or tool, adding much to both the facility and safety of operation. This type of starter is also adapted to remote control by means of a pressure gauge, float switch, or other devices which interpret conditions under which the motor is to be started and stopped. This form of starter is also very simply provided with overload protection, the circuit of the winding of the main switch being broken at the contacts of a small overload relay, as shown in the diagram Fig. 8.

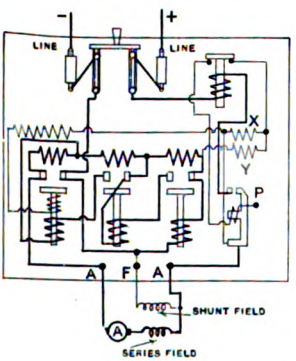


FIG. 8

The minimum number of accelerating switches which may be used in connection with a given motor depends rather upon the amount and character of the load than upon the size of the motor.

Digitized by Google

In general it may be said that when current limit acceleration is employed relatively very few subdivisions of resistance are required as compared with a manually operated starter. The number of subdivisions of the resistance in a manually operated starter is primarily determined as a matter of protecting the contacts of the starter itself. If too few subdivisions are used the drop between adjacent steps will be too high and serious burning or "bug ing" of the contacts will follow.

The automatic starter or controller with current limit acceleration is of course free of this limitation, and in addition possesses the advantage, as far as the motor is concerned, of cutting out successive sections of resistance only when the current in the circuit is at the proper value.

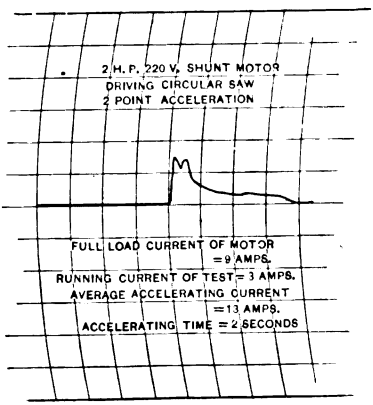

2 H. P. 220 V. SHUNT MOTOR
DRIVING CIRCULAR SAW
2 POINT ACCELERATION
FULL LOAD CURRENT OF MOTOR
=9 AMPS.
RUNNING CURRENT OF TEST = 3 AMPS.
AVERAGE ACCELERATING CURRENT
=13 AMPS.
ACCELERATING TIME = 2 SECONDS

FIG. 9

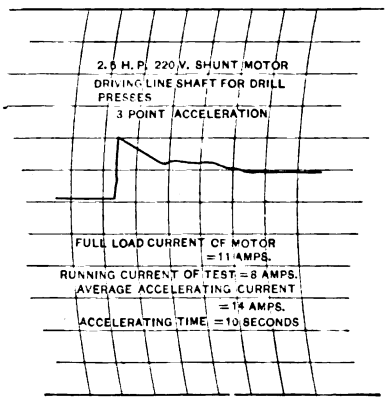


FIG. 10

For motors up to, say, five horse power, starting under light load or starting loads of small inertia, a single accelerating switch is sufficient.

For motors within the same range of horse power, starting at full load or starting loads of high inertia, (such as a machine equipped with a flywheel), two or even three accelerating switches may be required to keep the peaks of the accelerating current within prescribed limits.

Figs. 9, 10 and 11 are reproductions of accelerating current curves taken with a recording ammeter in the circuit of motors equipped with automatic starters of the "series current limit" type under consideration.

Fig. 9 shows the accelerating current curve of a two-h.p.

Digitized by Google

shunt motor driving a circular saw which starts under very light load. The starter in this case was equipped with but a single accelerating switch.

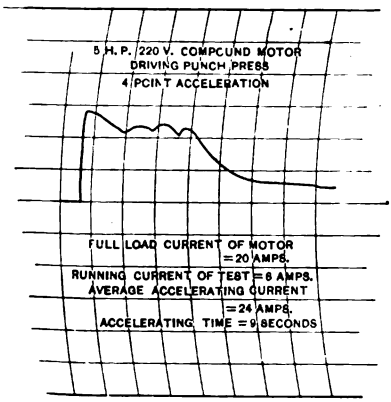

5 H. P. 220 V. COMPOUND MOTOR
DRIVING PUNCH PRESS
4 POINT ACCELERATION
FULL LOAD CURRENT OF MOTOR
=20 AMPS.
RUNNING CURRENT OF TEST = 6 AMPS.
AVERAGE ACCELERATING CURRENT
=24 AMPS.
ACCELERATING TIME = 9 SECONDS

FIG. 11

Fig. 10 shows the accelerating current curve of a $2\frac{1}{2}$ h.p. shunt wound motor driving a line shaft for light drill presses. The starter in this case was equipped with two accelerating switches, giving three points of acceleration including the operator's switch.

Fig. 11 shows the accelerating current curve of a five-h.p. compound wound motor driving a punch press, three accelerating switches being used. In general it may be said that for motors up to 25 h.p. three accelerating switches will be sufficient for all ordinary conditions, and for motors above this size from three to six or

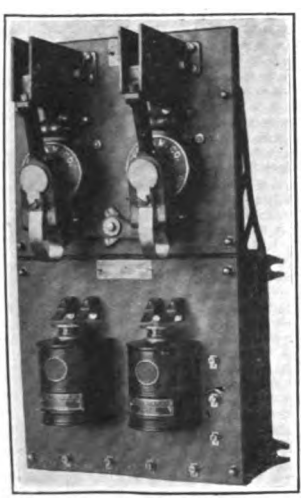


FIG. 12

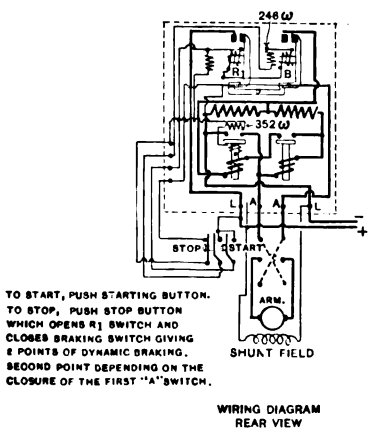


FIG. 13

more switches may be required. In any case it does not pay to extend the number of switches beyond a point governed by the sensitiveness of the switch itself.

Digitized by Google

The switch under consideration is sensitive well within ten per cent, that is to say, if the switch locks out positively at a given value of current it will close positively when the current has dropped ten per cent below that value. This means that the maximum and minimum accelerating current values can, with the requisite number of switches, be kept within five per cent above and five per cent below a horizontal line which represents a predetermined accelerating current of constant value.

In any calculations which are made as to the theoretically proper number of switches it must be borne in mind that the self-induction of the motor windings enters as an important factor, the peaks of current occurring at the instant of cutting out a given amount of resistance being in no case as great as a consideration of ohmic resistance alone would indicate.

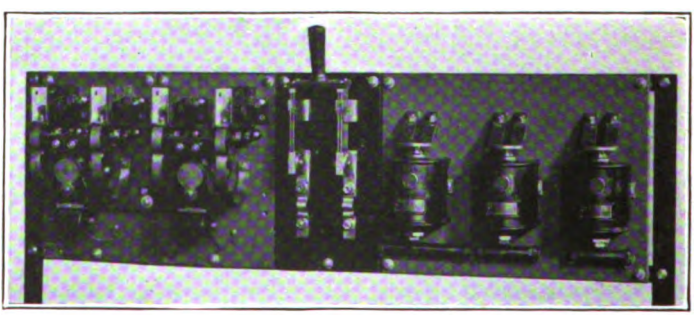


FIG. 14

Figs. 12 and 13 show respectively a front view and a diagram of connections of a special controller for governing motors driving certain kinds of machine tools such as boring mills and pipe threading machines. In addition to securing automatic current limit acceleration in the manner previously described, this controller provides for bringing the motor to rest promptly by means of dynamic braking, the braking current being also kept within safe limits by the current limit feature of the switches which govern the acceleration.

This starter is provided with a main switch having a shunt-wound actuating coil and a dynamic-braking switch constructed in like manner. The operator's control is through push-buttoms marked " start " and " stop " respectively. When the " start " button is pushed the circuit of the actuating winding of the main

Digitized by Google

switch is closed, causing this switch to close, and the starting resistance is then cut out automatically by the series wound accelerating switches in the manner previously described.

When it is desired to stop the " stop " button is pushed. This opens the circuit of the actuating winding of the main switch and closes the circuit of the winding of the dynamic braking switch, which then closes, establishing a local circuit across the armature, this circuit including the starting resistance and the actuating winding of the first resistance switch. As the motor slows down the dynamic braking current decreases and the first switch closes, thus cutting out a portion of the resistance in the dynamic braking circuit and at the same time closing the circuit through the winding of the second resistance controlling switch,

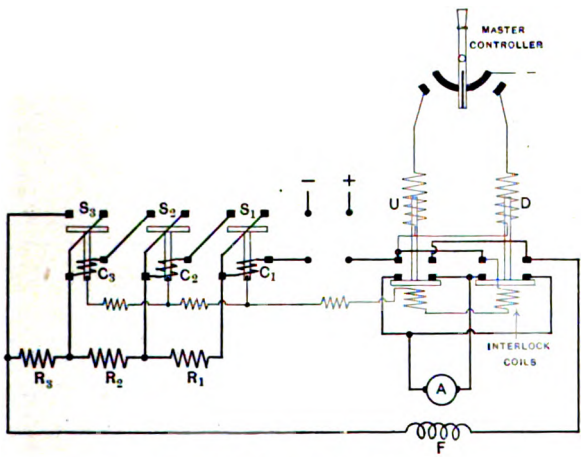


FIG. 15—Wiring Diagram

which in turn closes and cuts out a second section of resistance when the current has dropped to the value for which the switch is adjusted. Both the starting current and the dynamic braking current are therefore under automatic current limit control and are maintained within safe limits.

Fig. 14 is a front view of a 75-h.p. reversing controller specifically designed for steel mill service, and Fig. 15 shows the connections of this controller.

Reversal of the motor is provided for by two double pole magnetic switches having shunt wound actuating coils. The switches are mechanically interlocked in such a way that when one is closed the closure of the other is prohibited.

Digitized by Google

The actuating windings of the reversing switches are under the control of a suitable master controller in the hands of the operator. The motor circuit is initially closed at the contacts of one or the other reverser switches, this initial current flowing also through the winding of the first series wound switch. When the motor current has dropped to the predetermined accelerating value the first accelerating switch closes, short-circuiting the first section of resistance and establishing a circuit through the actuating winding of the second accelerating switch. The automatic cutting out of resistance continues in a similar manner till the motor is connected across the line.

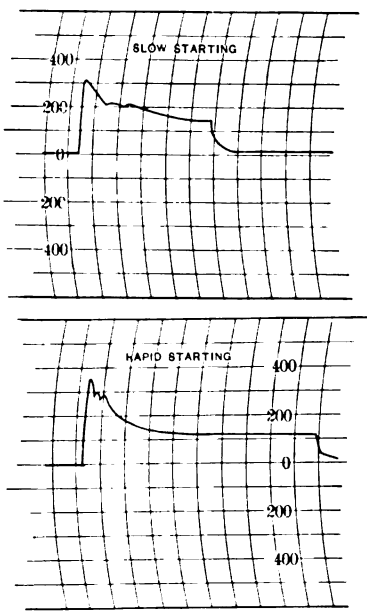


FIG. 16

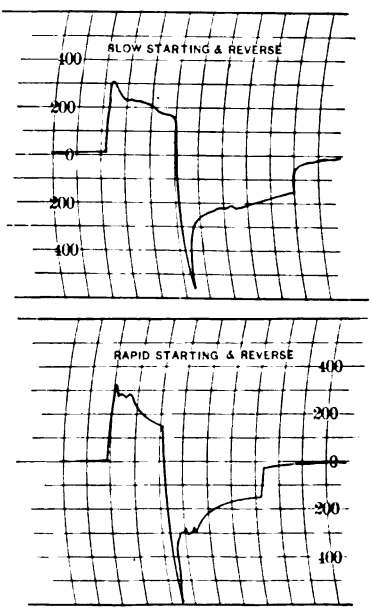


FIG. 17

The wiring diagram Fig. 15 shows a modified connection of the actuating windings of the accelerating switches, these windings being so arranged that they remain in series with the motor while the motor is running. A separate holding coil is therefore not required on the last switch.

As previously pointed out, the orderly or successive closure of the accelerating switches is provided for without the use of auxiliary or interlock contacts.

In a controller which is rapidly reversed it is essential to

Digitized by Google

provide that all of the starting resistance be in circuit when the motor connections are reversed. This is provided for by two "lock-out" magnets placed immediately below the movable members of the reversing switches in such a way as to lock them out, thus preventing closure of the switches when the magnets are energized. The windings of these magnets are so connected that they are energized whenever any of the accelerating switches is closed. The reverser therefore cannot be operated until all three of the accelerating switches have opened, thus inserting all of the resistance in the motor circuit. It will be observed that this interlock is also obtained without the use of auxiliary or interlock contacts. The entire controller is in fact stripped of all small and delicate parts, in view of conditions to be met in steel mill service.

FIG. 18

Figs. 16 and 17 are reproductions of accelerating current curves taken on this controller in connection with a 75-h.p.

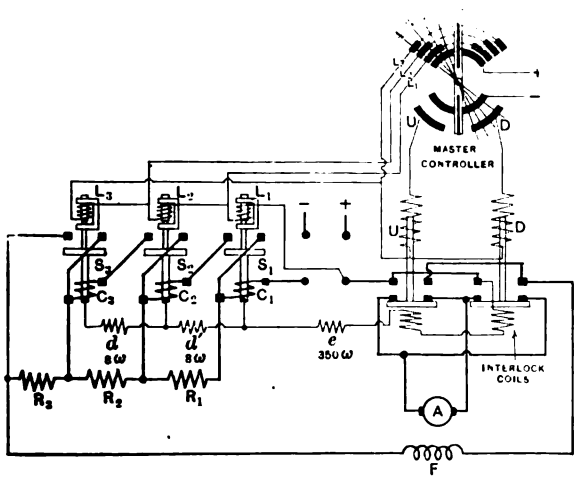


FIG. 19—Wiring Diagram

220-volt series wound motor. Fig. 16 shows the accelerating curves in simple starting, under different adjustments of the switches to secure slow and rapid starting.

Digitized by Google

Fig. 17 shows current curves taken under similar conditions, the motor being reversed. Since there is no arcing at the contacts of the accelerating switches they may be readily enclosed in such a way that their adjustment cannot be tampered with.

The controller illustrated in Figs. 14 and 15 does not provide for speed control. Where it is necessary that the operator have control of the speed of the motor, this is provided for by "holding-out magnets" which prevent actuation of the accelerating switches when the "holding-out magnets" are energized.

Fig. 18 illustrates a unit switch equipped with a "holding out magnet", and Fig. 19 is a diagram of connections of a controller arranged for speed control. It will be seen that the

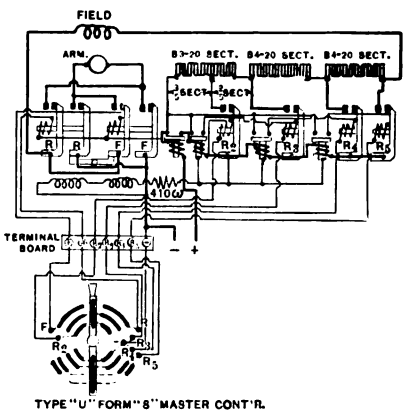


FIG. 20

"holding-out magnets" are successively de-energized as the master controller is moved toward the full speed position.

The series wound switch in addition to its functions of a combined switch and current limit relay is of course adapted for use as a simple current limit or acceleration relay in connection with switches having shunt wound actuating coils.

Fig. 20 is a diagram of connections of a controller arranged in this way. It will be observed that this form of relay stands normally in the open or safe position and successive switches cannot close till the corresponding relays have closed their contacts. This arrangement provides a further safety feature in that it protects the motor from danger due to open circuits in

Digitized by Google

the resistance and connections. The closure of successive resistance controlling switches depends not merely upon the closure of a preceding switch, but upon the closure of the main circuit controlled by a preceding switch. In case there is an open connection in the resistance controlled by one of the switches, the accelerating relay controlling the succeeding switch is not energized and the cutting out of resistance must stop at that point till the break is repaired.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

ELEVATOR CONTROL

BY T. E. BARNUM

The elevator problem is really one of service, and the general character of the elevator equipment must depend upon the character of service to be rendered. The service to be rendered by an elevator depends upon the number of passengers carried and the number of floors served; and is limited by the time taken by passengers entering and leaving the car, and the time required for acceleration and for retardation, as well as the actual time spent in traveling at full speed.

The engineer is then called upon to bring about the most effective combination of lifting power, speeds, acceleration and retardation for the requirements of a given building.

For the small office building with two or three elevators, express service to the upper floors is not possible, so that each elevator is required to stop at any floor. This often means stopping at every floor. Under these conditions the important factor is the ability to start and stop the elevator quickly and economically. The question of hoisting speed is of minor importance, as the schedule time for a trip depends so much upon the time taken to start and stop.

For the large office building, a sufficient number of elevators is provided, so that express service is possible on some elevators, and here the question of speed is of importance. However, for a part of the distance traveled local service must be rendered so that the capabilities of a quick start and stop can not be neglected.

In spite of the fact that the elevator may have to stop at every floor and that under these conditions it can not attain full speed, the capacity of the elevator in passengers per hour is a

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

maximum when the car is full, that is, starts with the car full to distribute the passengers to the several floors, and in returning reaches the main floor full of people. This result follows from the good speed regulation of the shunt motor over its full range of load. The condition is not the same with an hydraulic elevator as the speed varies with the load and the capacity of the elevator in passengers per hour is a maximum when loaded to 60 to 70 per cent of its capacity

Two types of electric elevators have been developed to meet these services; one, the worm gear drive with moderate speed motor, the other, the gearless drive with special slow speed motor. I propose to discuss these two principal types with special reference to office building requirements, and by an analysis of some control systems, and elevator performances to bring out their principal features.

The worm gear drive is used with a winding drum for short rises, and with the traction type of hoist when the rise is large, While the use of the worm gear results in a loss in efficiency from the motor to the load, this loss can be reduced to a reasonable amount by a correctly cut worm and worm gear, and the use of ball thrust bearings. The gear drive permits the use of a moderate speed motor of low cost, and high efficiency; and what is most important, with a wide range of speed control by field resistance. This speed control gives economical operation at a comparatively low speed and with certain classes of elevator service results in such an increase in electrical efficiency as compared to the gearless motor as to offset entirely the loss due the gear drive.

In general the best results have been obtained by using an adjustable speed motor with a 2 to 1 speed range by shunt field control. This gives an economical speed of one half of the maximum, which will be called the normal speed of the motor or elevator. Under a given load, the horse power output of the motor at this normal speed is one half its maximum, and it is possible to proportion the starting resistance and the current inrush for acceleration from this lower value, and obtain prompt acceleration. This also gives the operator positive control of the elevator speed, so that he can slow down to half speed quickly regardless of load. This also returns some power to the line.

It is, of course, necessary to give the operator a still slower speed in order that he may make an accurate landing easily. This slow speed is obtained by introducing resistance in series

Digitized by Google

with the armature and by shunting the armature with a section of resistance of low ohmic value relatively. In this way it is possible to give a slow speed of 25 per cent of the normal speed that does not vary very much with the load in the car. The elevator operator thus has an effective speed range of 8 to 1.

Diagram No. 1 shows in developed form the circuits for such an elevator motor. The switches of the controller are indicated by *X*. The motor armature circuit is controlled by three switches, the ***main switch***, and the two poles of the *reverse switch*. This arrangement also disconnects the armature resistance, the series brake coil, and the series field winding from both sides of the line in the " off " position of the controller. The shunt field of the motor is partially energized in the " off " position; the *field*

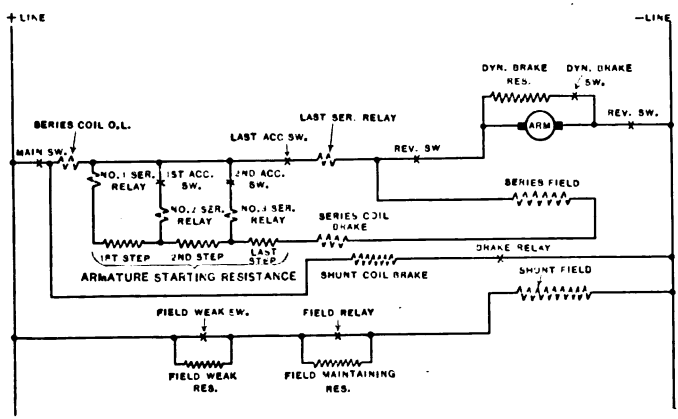


DIAGRAM NO. 1

weakening switch is closed but the *field relay* is open, leaving the *field maintaining* resistance in circuit. The principal reason for this is to obtain a quick start. The slow speed is obtained with the main, reverse switch and dynamic brake switches closed, and of course with full field strength by closing both the field weakening switch and the field relay. The coil of the dynamic brake switch is connected to the motor armature so that this circuit is kept closed in stopping until the motor comes practically to rest, and the braking effect of the current generated in this local circuit is available at all times to assist the mechanical brake.

Where the elevator runs at a fairly high speed, it is not possible to get a smooth stop from the mechanical brake alone without

Digitized by Google

excessive coasting. Excessive coasting is objectionable because of the varying amount of "coast" with varying loads. It is thus impossible to set the limit switches to stop the elevator with maximum load and to have the car come sufficiently close to the landing at light loads. The energy stored in the moving mass is proportional to the square of the velocity. The mechanical brake is capable of absorbing this energy in direct proportion to the velocity, only. While the dynamic brake will dissipate energy proportional to the square of the velocity, the mechanical brake is necessary, and a judicious combination of the two gives highly satisfactory results.

The mechanical brake is released by power and is applied by a spring or weight. The brake magnet has a series and a shunt winding; the brake being held released by the shunt winding only, but the two working together to raise the brake shoes. This arrangement reduces the size of the brake magnet and at the same time gives an interlock such that the brake cannot be released until the motor armature is connected to the line.

The acceleration is controlled by the four series relays. No. 1 series relay controls the cutting out of the first step of resistance, No. 2 the second step, No. 3 the third step, and the last series relay controls the opening of the field weakening switch, and therefore the increase in speed from normal to maximum. It has been found possible to cut the field weakening resistance into circuit in one step, and obtain a very smooth acceleration, because of the damping effect of the series field winding which is short circuited on itself through a path of low resistances. The field weakening switch is made so that an arc is permitted to form momentarily as the switch opens, thus assisting in the gradual reduction of the shunt field current. This arrangement for weakening the field gives a very smooth acceleration and simplifies the controller.

Diagram No. 2 shows in developed form the control circuits for this elevator. The car switch lever is a segment which connects contacts 1, 2, 3 and 4, either side of the "off" position. In general the opening of a control circuit any where results in the slowing down or the stopping of the elevator. The coils of switches controlling directly the starting of the motor are in series, these being the two coils of the reverse switch, the brake relay and the main switch. The brake relay opens one side of the line to the shunt brake coil, and also operates the shunt field relay. This circuit is opened to stop the elevator by the

Digitized by Google

operator from the car switch, by the machine limit switch, which is two-pole, by the overload relay, by the overtravel limit switches, by the overspeed switch, by the slack cable switch or by the car safety switch. If the car is stopped by the machine limit switch, as is the case ordinarily, the operator may reverse the elevator by reversing the car switch. If the overload relay stops the car, the shunt coil of the relay connected to contact No. 1 holds the relay up and its circuit open until the car switch is moved to the "off" position. The overload relay can thus be reset at any time from the car switch. If the car is stopped by any of the other switches, it can not be started again until some one goes to the machine and takes care of the part causing the switch to operate. The slow speed relay controlled through contact

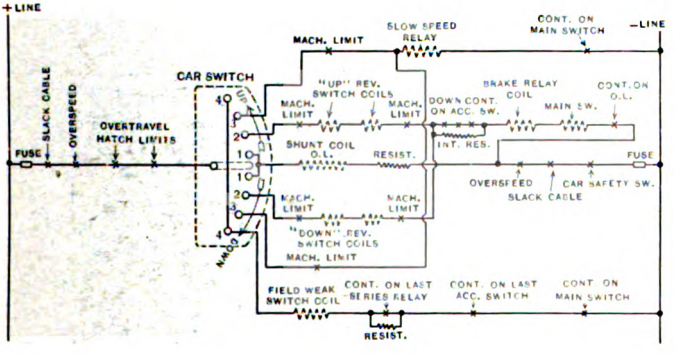


DIAGRAM NO. 2

No. 3, controls the set of switches for accelerating the car, and the dynamic brake switch. When this circuit is opened the armature resistance is cut into circuit and the dynamic brake switch is closed. The machine limit switch also opens this circuit to slow the motor down before stopping. The field weakening resistance is cut into the field circuit by energizing the field weakening switch, so that opening this circuit slows the elevator down to normal speed.

Also as far as possible switches in the main control circuit are double pole, or the equivalent. Although the car switch itself is single pole only in one side of the line to the controller, a car safety switch is installed within reach of the operator which is connected by a separate two-wire cable in the other side of the line to the controller. The machine limit switch, slack cable

Digitized by Google

switch, and overspeed switch are double pole, as shown. Of course, where the machine is of the traction type, the limit switches are installed in the hatchway, and operated by the car itself.

In the circuit including the main switch and reversing switch is an interlocking resistance so proportioned that the switches will not close if this resistance is in circuit. This resistance is short circuited only when all of the resistance switches are open, so that the motor circuit cannot be closed unless all the armature, starting resistance, the series field and the series brake coil are in the circuit. This arrangement makes it possible to reverse the elevator quickly, or to " plug " the motor.

Fig. 1 illustrates the switchboard of a controller having general connections as shown in Diagrams 1 and 2. The performance of such a controller is illustrated by Curves No. 1, 2 and 3. These and the other curves shown were taken by two recording ammeters, coupled together so as to synchronize. One ammeter was connected in the armature circuit and the current indicated by this instrument is shown by the full line. The other instrument was connected in the line circuit and this current is shown by the dotted line. Having these curves and knowing what the various current peaks mean, it is possible to tell just what the motor was doing.

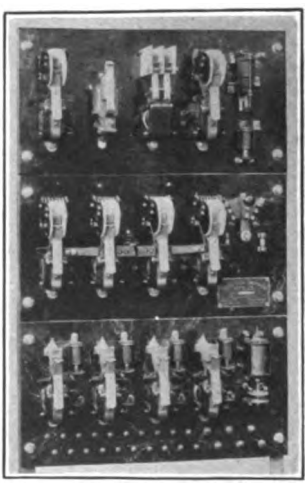


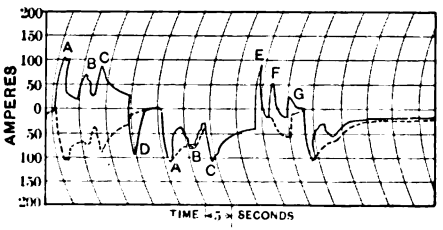
FIG. 1

In order to show what the various current peaks mean, the car switch was moved to the full speed position step by step. The result is shown by Curve No. 1. Current peak *A* is obtained when the car switch is moved to the first or slow speed position. While running on this point the line current is greater than the armature current, as the armature is shunted by the dynamic brake resistance. Current peak *B* is obtained when the car switch is moved to the second or normal speed position. This opens the shunt around the armature and cuts out the starting resistance. Current peak *C* is obtained as the switch is thrown

Digitized by Google

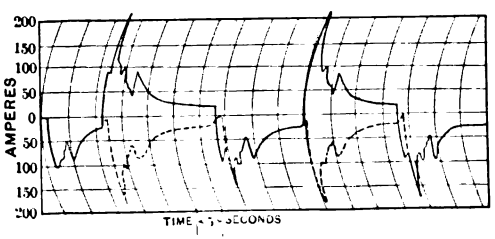
to the third or maximum speed position, weakening the shunt field and doubling the speed of the motor and elevator. The car switch was then thrown quickly to the " off " position, giving the dynamic brake current peak *D*. The car switch was then thrown in the reverse direction, reversing the elevator, and giving the same three current peaks *A*, *B* and *C*.

The car switch was then moved step by step to the " off "



CURVE NO. 1

position. Moving the switch back to the normal speed position strengthens the shunt field and gives current peak *E*. It is to be noted that some current is here returned to the line, changing from a positive or power current of about 50 amperes to a negative or braking current of about 90 amperes. Moving the switch to the slow speed position gives current peak *F*, and moving the switch to the " off " position gives current peak *G*.

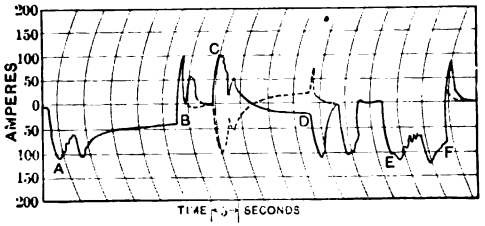


CURVE NO. 2

Curve No. 2 was taken from the same elevator, showing first automatic acceleration from rest, and then " plugging " the motor. The steps of armature resistance and the weakening of the field can be seen readily. Note that the controller always starts to cut resistance out of the circuit at about 100 amperes. This is the result of the series relay system of automatic acceleration. Note also the decreasing peaks of current. It might

Digitized by Google

be thought that a jar would be felt in the car when the field is thus weakened in one step, but this is not so. The acceleration is very smooth. Note also the overlapping of the armature cur-



CURVE No. 3

rent, showing the dynamic brake slowing the motor down before power is applied in the reverse direction. This is due to the time element of the switches and the electrical interlock. It is possible to add a second interlock which will make it impossible to reverse until the motor has come to rest. The ability to reverse quickly is always preferred by the owner as it saves time.

Curve No. 3 was taken from the same elevator to show the variation of the time taken to accelerate with the load. Curve *A B* is hoisting a fair load. The elevator was then slowed to normal speed and then stopped. Curve *C D* is lowering a heavy load. Note that current is being returned to the line when the elevator is running at maximum speed. Curve *E F* is hoisting a very heavy load.

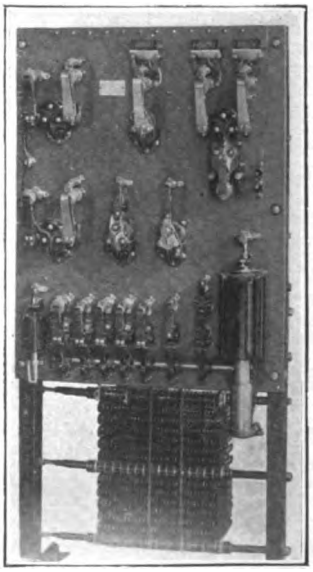


FIG. 2

Curves 1, 2 and 3 were taken from a 30-h.p. 230-volt worm gear traction elevator running at 350 ft. per min.

Dash pot timing of the acceleration also gives satisfactory results. Fig. 2 shows a controller with dash-pot acceleration, and Diagram No. 3 shows the general control circuit connections.

Digitized by Google

In general the scheme of connections is the same as for Diagram No. 2. The performance of such an elevator is shown by Curves No. 4 and 5. This was a worm gear drum machine operating at 350 ft. per min. and driven by a 25-h.p. 220-volt motor having a speed range by field control from 525 to 850 rev. per min. This controller gave two speeds only, normal and maximum. The dynamic brake was applied only in the " off " position to assist the mechanical brake. Referring to Curve No. 4; curve *A B* shows acceleration of a fair load, current peak *C* shows acceleration from rest to normal speed of a heavier load. The increasing starting current with constant time of acceleration may be noted. Current peak *D* occurs as the field is weakened to accelerate to maximum speed. The car switch was then thrown back to normal speed, giving current dip *E*, and then to the " off "

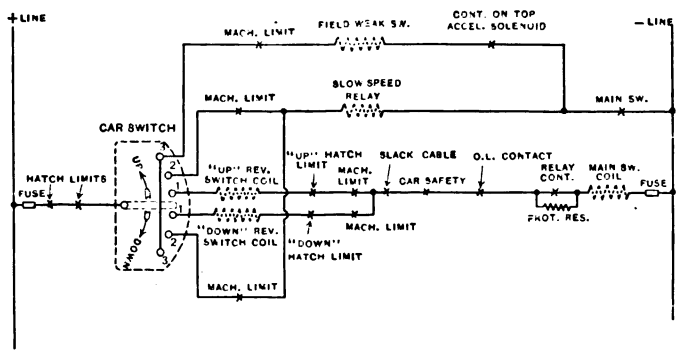
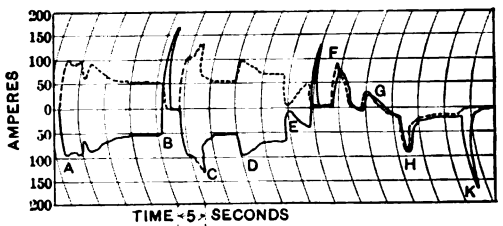


DIAGRAM NO. 3

position. The elevator was then reversed to lower the heavy load. Current peak *F* is accelerating to normal speed, and *G* accelerating to maximum speed. The elevator was then slowed down to normal speed, giving current peak *H*. Note that current is being returned to the line. Throwing the switch to the " off " position gives the dynamic brake peak *K*. Curve No. 5 was taken from the same machine to show operation under various loads. Curve *A B* is hoisting a heavy load, curve *C D* is lowering a heavy load. The motor was then " plugged ". The retarding effect of the dash pot permits the motor to come nearly to rest before power is applied in the reverse direction. The electrical interlock between the starter and the main switch prevents this switch from closing until the starting resistance is included in the armature circuit.

Digitized by Google

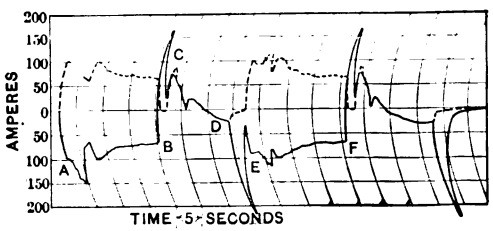
There are often cases where an elevator must lift a very heavy load once in a while, but ordinarily is required to lift much lighter loads. In some cases an elevator handles both freight and passengers. It is here desirable that the elevator operate at a fairly high speed when carrying passengers or light freight. The worm gear elevator with an adjustable speed motor having a 2 to 1 speed range, fits in here very well. Such a motor will



CURVE NO. 4

develop its rated out-put at its normal speed as well as at its maximum speed, and will lift double the normal load at half speed safely and satisfactorily.

As noted before, however, the armature starting resistance is proportioned for normal duty to the reduced horse power output at normal speed. When a heavy load is to be lifted a switch on the controller board is closed, which connects a section of re-



CURVE NO. 5

sistance in parallel with each step of the regular resistance, and at the same time opens the control circuit to the field weakening switch. This arrangement gives the necessary current in-rush to start the heavy load, and makes it possible to lower this heavy load safely.

Such a controller is shown in Fig. 3. The double-pole switch is the switch connecting in the extra starting resistance. This

Digitized by Google

is a worm gear traction elevator running at a maximum speed of 400 ft. per min., and driven by a 25-h.p. 220-volt adjustable speed motor having a 2 to 1 speed range. This elevator is in an 18-story office building. It is used for freight ordinarily but carries passengers at night when the other elevators are shut down. The performance of this elevator is shown by Curve No. 6. Curve *A B C* is going down light, showing the load of hoisting the counterweight. Peak *D* occurs when slowing down to normal speed. Peak *E* is the dynamic brake current when controller is thrown off. Curve *F G* is hoisting a light load. Curve *H K L*

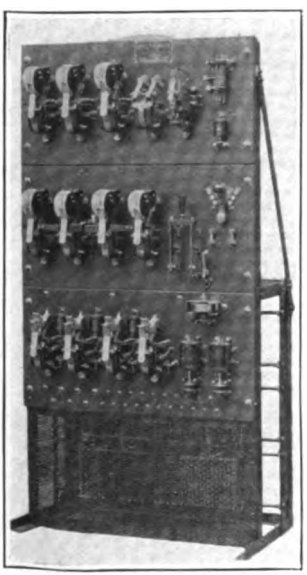
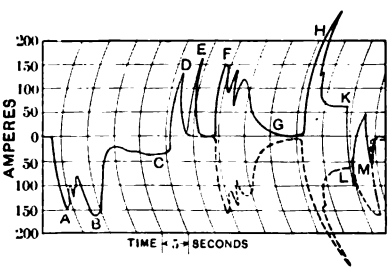
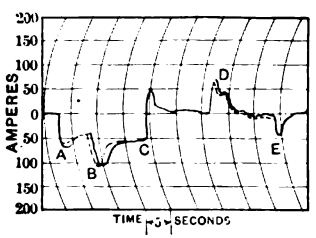


FIG. 3



CURVE NO. 6



CURVE NO. 7

was taken when hoisting a safe, with the special switch closed. *H* is the starting current and *K* the running current. With such a heavy load the friction of rest is high requiring a heavy starting current. Peaks *L* and *M* occurred as the elevator was slowed down and stopped.

As shown in the connection diagrams, the shunt field of the motor is partially excited when the elevator is at rest. This arrangement gives a quicker start than is the case when the field circuit is opened, and results in a saving of both time and energy. A test was made on an elevator to show this. The motor was 20 h.p., 220 volts, having 15 per cent compounding while ac-

Digitized by Google

celerating, and 2 to 1 speed range by shunt field control. The elevator had a maximum speed of 350 ft. per min. The results of this test are shown in Curve No. 7. The full line shows the armature current and time required to accelerate from rest with the shunt field circuit broken in the off position; while the dotted line shows the current and time under the same load conditions when the field is partially energized in the "off" position.

A careful measurement of the original curves shows that when accelerating a heavy load, it requires 4/5 of a second longer to get under way, with an average load about 3/5 of a second longer, and with a light load 2/5 of a second longer. Curve *A B C* was taken hoisting a heavy load, and curve *D E* lowering a heavy load, thus showing the two extremes.

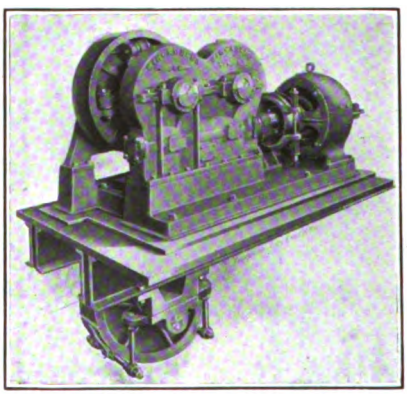


FIG. 4

When partially energized, the field takes 1.4 amperes at 226 volts, and consumes power at the rate of 308 watts. This is sometimes considered a waste of energy. Taking the average extension of the accelerating period as 3/5 second, and the starting current under these conditions as 65 amperes, the extra energy consumed during one start is 143 watt-minutes. This is as much energy as the shunt field consumes with the elevator at rest for a period of 28 seconds, or nearly half a minute. This elevator was in a 10-story building and outside of the busy period would sometimes make as few as two stops each way during one round trip. Under these conditions the trip requires one minute, and the extra energy taken at starting will make up for an idle

Digitized by Google

period of two minutes. In order that there should be any saving of energy by opening the field circuit the elevator would have to stand idle more than $\frac{2}{3}$ of the time. Of course, where the elevator is to stand idle for any length of time, it pays to open the service switch, which may be of the remote controlled type where the controller is at the top of the hatchway.

The usual arrangement of the worm gear machine is shown in Fig. 4. The gears are spiral gears and intermesh so that both worms drive the one sheave. An idler sheave is mounted below the driving sheave, and each hoisting cable passes first over the driving sheave, one half turn, then under the idler, and again one half turn over the driving sheave and down to the counterweight. Each cable thus makes one complete turn around the driving sheave, which gives the necessary traction.

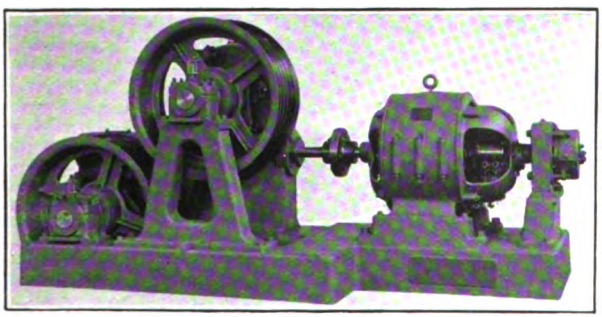


FIG. 5

Fig. 5 shows a very interesting arrangement whereby the motor drives both sheaves. The gears do not intermesh, as the thrust is taken up by the system of roping. The traction thus obtained is very high. Fig. 6 shows another view of the motor and disk brake of this machine, and the general arrangement of the controller boards. The motors have a speed range by field control from 300 to 825 rev. per min. There are three of these elevators serving an 18-story building and having a maximum speed 400 ft. per min. Owing to the wide speed range the change of speed from normal to maximum is made in two steps. As before, a speed of 25 per cent of the normal is obtained, thus giving the operator a speed control range of 11 to 1. These elevators are very busy all day and stop at all floors.

The gearless traction elevator is very generally used for large

Digitized by Google

office buildings. Fig. 7 and Fig. 8 show one of these machines and the corresponding controller board. It will be noted that the machine is very simple, although it is mostly all motor, and that the controller board is more complicated than those for the geared machines. That this must be so will be seen from a consideration of what the controller must do.

This machine is driven by a slow-speed motor, 35 h.p. at 230 volts, having a normal speed of 43 rev. per min., and a maximum speed of 55 rev. per min. This is a comparatively narrow range. The maximum speed of the motor is limited by the consideration that the diameter of the hoisting sheave should not be less

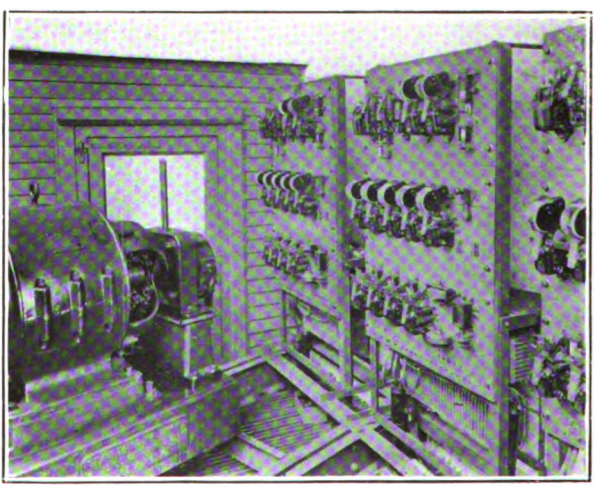


FIG. 6

than about 38 inches on account of the hoisting cables. The maximum speed of this elevator is 550 ft. per min., and the normal speed 430 ft. per min. The controller must then be capable of reducing the elevator speed to about 15 per cent of the normal speed with any load in the car. This is done by a combination of resistance in series with the armature, and resistance in shunt to the armature.

Diagram No. 4 shows the main motor circuits of this elevator. The general scheme is the same as for diagram No. 1, with the addition of several switches to control the armature shunt resistance. Five speeds are provided for the operator in the car,

Digitized by Google

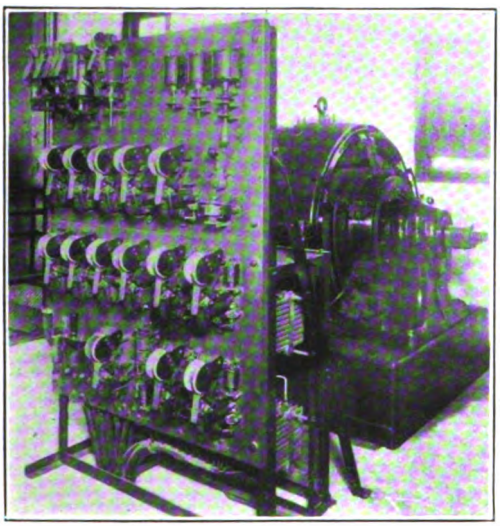


FIG. 7

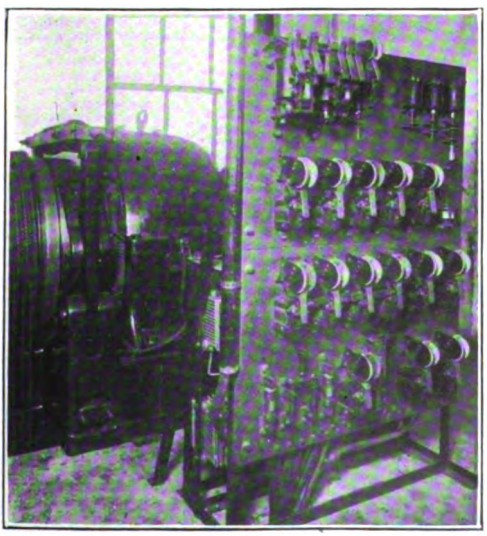


FIG. 8

Digitized by Google

the maximum speed, the normal speed, and three slow speeds obtained by dynamic brake switches 1, 2 and 3. The 4th dynamic brake switch is used in connection with the limit switches for varying the dynamic brake effect with the load in the car. It will be seen readily that the electrical efficiency of this equipment is low at the slow speeds.

Dynamic brake switches 1 and 2 are closed with power from the line, while switches 3 and 4 are connected to the armature terminals and their closure depends upon the counter-electromotive force. Position No. 5 of the car switch gives the maximum speed with weakened shunt field; position No. 4 gives the normal speed with full field; position No. 3 gives the third slow-

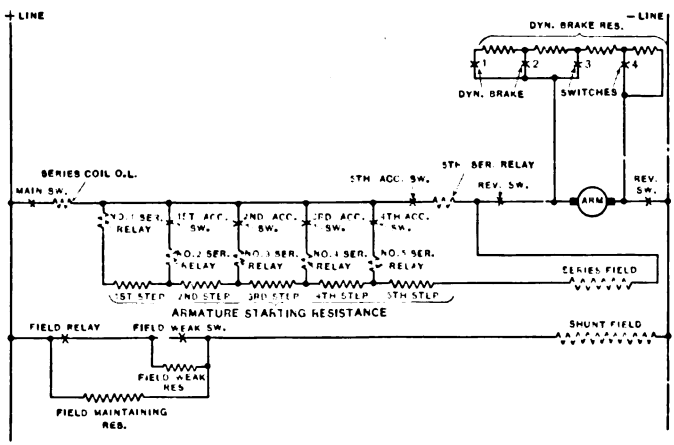
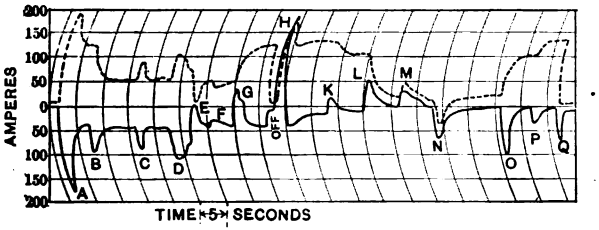


DIAGRAM NO. 4

speed with all the armature resistance in circuit and dynamic brake switch No. 1 closed; and position No. 2 of the car switch gives the second slow speed by closing dynamic brake switch 2. In this second position the coil of dynamic brake switch 4 is also connected to the armature terminals. If now the speed of the motor should be high, as when lowering a heavy load, the voltage at the motor terminals will be sufficient to close *D B* switch 4, thus automatically reducing the shunt resistance to regulate this slow speed. Position No. 1 of the car switch connected *D B* switch 3 to the armature terminals, and the closure of this switch also depends upon the load. In hoisting a heavy load *D B* switches 3 and 4 will not close as the speed of the elevator

Digitized by Google

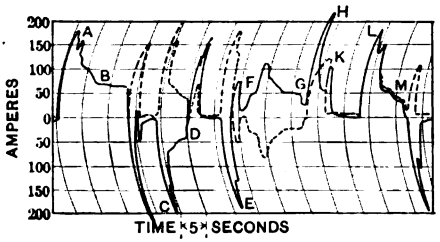
will be sufficiently slow without them. With an average load switch 3 will close but switch 4 will not; while with a light or negative load both 3 and 4 will close. This automatic adjustment of the armature shunt resistance is necessary in order that the car may be stopped positively and accurately at the upper and lower landings by the limit switches, regardless of the load in the car; and is also of assistance to the operator in making the



CURVE NO. 8

intermediate landings accurately. This is of considerable importance since any time wasted in bringing the car to rest at a floor means a reduction in the capacity of the elevator.

Curves No. 8 and 9 will show something of the performance of this elevator equipment. In Curve 8 the car switch was first thrown to the maximum speed position step by step, the elevator going down empty. Peak *A* is the starting current. The opera-



CURVE NO. 9

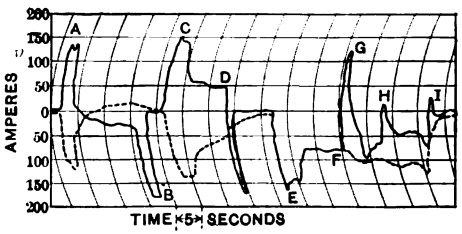
tor apparently passed almost immediately to the second point, and the running current is that taken in the second slow speed position. Note here that the armature current is 37 amperes, while the line current is 123 amperes. However, of this latter value the shunt field is taking 12 amperes, and additional current is taken by the brake magnet and the solenoid switches of the controller. Current peak *B* occurs when passing to the third

Digitized by Google

slow speed, *C* when passing to normal speed, and *D* when passing to the maximum speed. The elevator was then slowed down gradually. Current dip *E* occurs when passing to normal speed, and *F* and *G* show 2 of the slow speeds.

The elevator was then reversed and the car switch manipulated in the same manner. Peak *H* is the starting current going up light. Note that on the two slow speed points showing, the armature is generating some current, but that a heavy current is still being taken from the line. Peak *L* is accelerating to normal and *M* to maximum speed. *N* is slowing down to normal speed, and *O P* and *Q* are the three slow speeds.

Curve 9 shows something of the regular service conditions. Curve *A B* is hoisting a heavy load, *C D* lowering an average load. Beginning at *E*, the curve shows the start and run, and then the slowing down and stopping of a very heavy load. Note



CURVE NO. 10

that for the part *F G*, a heavy current is sent back to the line. *L M* is hoisting the average load.

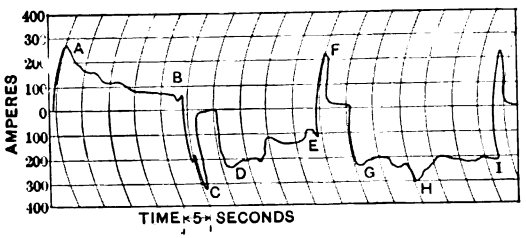
Curve No. 10 shows the performance of gearless traction elevator controller having the counter e.m.f. system of acceleration where the armature resistance is cut out as the counter e.m.f. rises. As before, the slow speeds are obtained by shunting the armature. *A* is going down with a load, and *B* is the braking current, *C D* is going down light. *E F* is hoisting a heavy load, and peaks *G*, *H* and *I* show the current when slowing down gradually. As a basis of comparison the elevator of curves 8 and 9 has a capacity of 18 passengers at 550 ft. per min., while the elevator of curve 10 has a capacity of 12 passengers at 550 ft. per min. The motors have the same rating and about the same maximum speed, but I do not know the speed range by field control of the motor of curve 10.

Comparing the two systems of acceleration, the counter

Digitized by Google

e.m.f. system is affected by line voltage variation much more than is the series relay system. In the series relay controller the adjustment of the relays is independent of the line voltage, and as the switches will function at any voltage from normal to 20 per cent below or to 20 per cent above, the motor will be accelerated at any voltage within this range with the same current value. In the counter e.m.f. system, the accelerating current will vary greatly with the line voltage, reaching an objectionably high value if the voltage is high; or falling so low with a low voltage that the starting resistance may not be cut out, or the time for acceleration becomes objectionably long. If the line voltage is constant, the two systems will give the same results.

Dash pot control of the acceleration gives a constant time for the cutting out of the armature resistance, which results in a slower start at light loads, and a high starting current at heavy



CURVE No. 11.

loads. With a motor of proper size and character the dash pot system may be made to give results as satisfactory as with the other systems. However, the tendency in this system is to make the accelerating period longer than with the other two. Curve No. 11 shows an exaggerated case. This is a special elevator running at 575 ft. per min., and driven by a 30-h.p. 115-volt moderate speed motor. There was no speed control by field variation, but the acceleration was controlled entirely by armature resistance. There were no slow speeds, but a dynamic brake was applied in the " off " position to assist the mechanical brake. Curve *A B* is going down light, showing the load of hoisting, the counterweight. Current peak *C* is the dynamic brake. Curve *D E* is hoisting an average load and peak *F* is the corresponding dynamic brake current. Curve *G H I* is hoisting a heavy load, the part *G H* being the accelerating current with an accelerating period of about 10 seconds. This long time is of course neces-

Digitized by Google

sary where the starting current exceeds the running current by such a small margin.

The energy required to run an elevator depends upon the service rendered, so that in many ways the power consumption basis of comparison is unsatisfactory. The following results of a test of a gearless traction elevator will show this. Running the empty car, but stopping at every floor both ways required 6.4 kw-hr. per car-mile. Running the car with maximum load and stopping at all floors required 10.4 kw-hr. per car-mile. Running with $\frac{2}{3}$ load, but stopping top and bottom only, required but 2.4 kw-hr. per car mile. Stopping at all landings with $\frac{2}{3}$ load required 8.8 kw-hr. per car-mile.

In a 22-story office building equipped with gearless traction machines the express elevators serve the 10th floor and above, and run at 600 ft. per min. They make about 22 miles per day with a power consumption of 3.5 kw-hr. per car-mile. In the same building the local elevators, serving the first to tenth floors, run at 400 ft. per min., and make about 9 miles per day with a power consumption of 4 kw-hr. per car-mile.

The gearless machines of Figs. 7 and 8 serve an 18-story office building, making all floor , and require 3.44 kw-hr. per car-mile. In the same building the worm gear traction elevator whose controller is shown in Fig. 3 and performance by curve No. 6 require 3.58 kw-hr. per car-mile.

The worm gear elevators of Figs. 5 and 6 serve an 18-story office building stopping at all floors, and make an average of 21.8 miles per day with a power consumption of 3.28 kw-hr. per car-mile. The elevators similar to that of Fig. 4 serve a 13-story building, running at 400 ft. per min. They make about 19 miles per day with a power consumption of 3.88 kw-hr. per car-mile.

A worm geared drum machine having a controller like that of Fig. 1, makes 12.9 miles per day, at a maximum speed of 240 ft. per min. The average consumption of energy per car-mile is 2.76 kw-hr. The average of a number of worm-gear elevators. each having a maximum speed of 400 ft. per min., give a power consumptionof 3.8 kw-hr. per car-mile. An average of the gearless elevators running at 550 ft. per min. gives 3.5 kw-hr. per car-mile.

On the side of mechanical simplicity and efficiency the gearless machine has the advantage. The motor at maximum speed and 75 per cent load has an efficiency of 80 per cent, and at normal

Digitized by Google

speed and 75 per cent load an efficiency of 67 per cent. At half load, which is nearer the average condition, the efficiency is 58 per cent at normal speed and 76 per cent at maximum speed. Also as noted above the electrical efficiency is greatly reduced where the elevator is operated at the slow speeds. The controller is more complicated but not less reliable, and the necessary elements for security are readily provided. The mechanical arrangements also facilitate smoothness of operation, which is a very desirable feature.

In the geared machine the mechanical efficiency is lower, but this introduces a factor tending towards greater security; there is a reduced tendency to run away. The moderate speed motor of this machine has an efficiency at half load of 90 per cent at maximum speed, and 78 per cent at a normal speed one half the maximum. At 75 per cent load the efficiency is 91 per cent at maximum speed and 81 per cent at normal speed. This increased motor efficiency will nearly make up for the reduced mechanical efficiency at maximum speed, and at one half speed will more than make up for it.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.
(*Subject to final revision for the Transactions.*)

SOME LIMITATIONS OF RHEOSTATIC CONTROL

BY G. R. RADLEY AND L. L. TATUM

We may consider the limits of rheostatic control under three classes, *functional*, where the limitations are inherent to the type of control; *resistance material*, where the limitations are due to physical characteristics of the rheostat material, and *switching devices* where the limitations apply to the method of adjusting resistance.

Functional Limitations

Under this heading, there are two general classes, those in which the load is predetermined, and absolutely under the control of the operator such as a field rheostat, and those in which the load is dependent on a variable factor, not absolutely of a predetermined value such as a motor speed regulator with varying load on the motor.

In the first type, the field between actual physical limits is wide, but commercial limitations are worthy of consideration. Inherently all such devices are heat dissipators and the most important commercial limitation is the compromise of three variables; watts to be dissipated, allowable temperature rise, and physical dimensions. The discussion of these limitations which are common to all forms of rheostatic devices will be taken up later under the subject of "Limitations of Resistance Material."

Fineness of regulation is commercially limited. A field rheostat must be able to adjust the voltage of the generator by reasonably fine increments throughout the working range both of load and of speed of prime mover. If the range is wide, and the regulation desired is fine, the number of steps to obtain this range increases and while no physical limitations appear, the cost is increased. A fineness of regulation closer than $\frac{1}{2}$ of one per cent of the rated voltage is ordinarily unnecessary, and generally

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

this fineness may be obtained with a variation in excitation current of 1.5 per cent per step. For most machines 60 steps, thus representing in the neighborhood of 25 or 30 per cent of line voltage variation is ample. If, however, the major portion of this 25 per cent variation is outside the normal working range, then this number of steps may be insufficient. This condition may be overcome by the introduction of coarse steps in that portion of the range which is not normally used. For voltages above the working range, a single fixed step of resistance may serve to throw the normal voltage into the center of the adjusting range. Similarly below operating voltages a few coarse steps may be wanted for lowering the voltage to a satisfactory point for cutting out a generator.

Fineness of stepping over a wide range affects the size by increasing the watt dissipating material, as well as by increasing the number of switching points. Coarse steps tend to cheapen the rheostat but there are limits in this direction which will be discussed under contact limitations.

When a generator is capable of voltages much above normal, a fixed step of resistance results in economy of wattage capacity in the rheostat without approaching the contact limits, protects the machine from excessive heating of fields, and prevents excessive voltage on the line.

For use with automatic voltage regulators which require a wide range of generator excitation, coarse steps over most of the range with fine steps around normal, for possible hand regulation, reduces the size of the rheostat materially.

Another class of rheostatic device very similar in its functions to the field rheostat is the lamp dimmer. Here the conditions are even better defined than for the rheostat, as the dimmer is connected across a constant voltage supply in series with a quite definitely known resistance. The same general limitations, apply however: The coarser the stepping the smaller and cheaper is the rheostat.

Typical of the second class, namely, the type of control where there exists in the circuit a variable element which may be independent of the adjustment of the rheostat, are motor starters, or speed regulators where the counter voltage of the motor may be dependent on the load as well as on the adjustable resistance. Arc lamp resistances are more or less similar in their behavior. For this type of apparatus the governing feature is "load". Ohm's law must ever be in mind in considering such devices.

Digitized by Google

For a fixed value of R, E will vary directly as the current in the resistance, and when used as a speed regulating device across a constant potential line, the difference between the voltage drop in the resistance and the line voltage must be the counter e.m.f., of the motor. If the load on the motor varies, as when driving a machine tool such as lathe or planer, the voltage drop across the resistance must vary in direct proportion and the motor speed will vary inversely as the load. The inherently bad effect of such instability of speed regulation on machine tool work is too well understood to need discussion.

Where the load of the motor at any speed is approximately constant as when driving fans, pumps, printing presses, long line shafts, etc., resistance control is practical, although not always economical. Where the required torque decreases with the speed, as in the case of fans or centrifugal pumps the use of resistance is economical, since it reduces the current taken from the line, but where the torque is constant as for plunger pumps or positive pressure blowers, the only economy obtained by such control is in reduction of wear and tear on the apparatus, although convenience may warrant its installation independent of economical considerations.

On motor starters or regulators, the limit of coarseness of stepping is the increase in voltage the motor will stand without objectionable surge of current. This is a function of the motor and line resistance. A low motor resistance means a large current with small voltage rise at its terminals. A small high resistance series motor may not take an objectionable surge even if given full line voltage, while a large shunt-wound machine may not stand more than a few per cent voltage increase without excessive currents. This limit cannot be predetermined accurately as the inductance of the circuit, reaction of armature current surge on field strength, and momentary acceleration all tend to damp out the high peaks and give less than the calculated current surge for a given voltage increase.

This limit of stepping of resistance is most pronounced with the motor near normal speed or with little resistance in circuit. Theoretically for a 50 per cent overload surge we should be able to reduce the ohms in circuit to $\frac{2}{3}$ the previous value whenever the current has fallen to normal. This means that the ohmic value of the steps decreases toward the short circuit end.

This limits the arrangement of the steps on speed regulators since a regulator must also perform the functions of a starter.

Digitized by Google

If equal percentage increase in speed per step is wanted, (a geometrical progression) the last steps must be larger than the first, but this is the reverse of what is possible with equal surges. If equal speed increments are wanted, (an arithmetical progression) the steps should be of equal ohms, approaching more nearly to the starting requirements, but a compromise between the desirable speed curve and good starting characteristics must generally be made.

While the coarseness of steps is thus limited, there is no functional limit to the fineness of them, commercial considerations alone governing this.

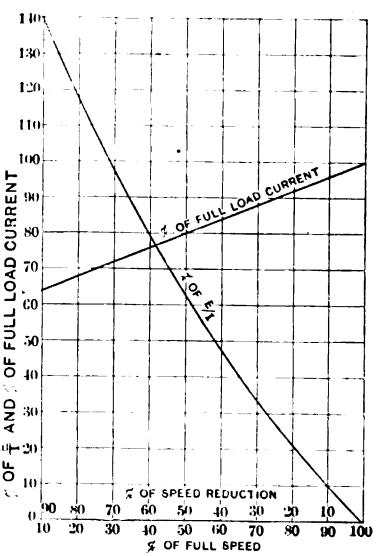


FIG. 1—Relation between speed, current and resistance assumed for machine regulation design.

Two distinct types of armature speed regulating devices are commercially recognized. These are commonly known as "machine type" and "fan type". Machine type is suitable for motors where the torque or current necessary for operation of the motor is approximately constant.

Fan type is the term applied to devices where the torque falls off as the speed decreases. As it is often impractical to determine the actual load a motor is to drive, one manufacturer designs a machine type regulator for 50 per cent reduction in

Digitized by Google

speed with 80 per cent of the rated motor current thus allowing for the desired speed regulation with a 20 per cent variation in the actual load. If the motor runs at its full rated current, the speed reduction possible with all resistance in circuit will then be 62½ per cent.

The relation of resistance necessary to give any desired decrease in speed on the assumption that the load current follows a straight line from full load at full speed to 80 per cent of load at half speed is given in Fig. 1. The resistance is expressed in per cent of line volts divided by rated current of motor, thus making the formula applicable for all voltages and motor ratings. Fig. 2 shows a similar curve as laid out for the typical fan load. Theoretically, the horse power of a fan varies as the cube of the

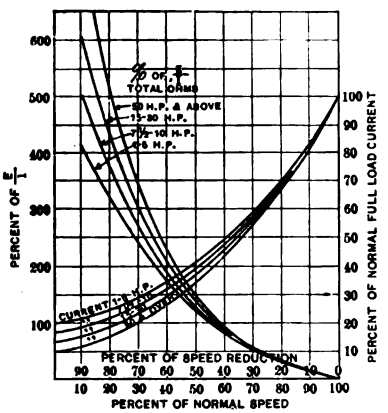


FIG. 2—Curves for fan regulation by armature resistance.

speed. Its torque therefore varies as the square of the speed and the current in the armature circuit should vary as the square of the speed. The friction losses will, however, vary directly as the speed, so that the total current in the motor armature should vary along a line between a straight line and the square curve. The effect of the friction losses will be much greater with small fans and at low speed and Fig. 2 therefore gives several current curves for motors of different sizes, the large sizes approaching more closely to a square curve, while the small sizes more closely approach a straight line.

From an inspection of these curves the fact becomes apparent that the characteristics of the load, including its limiting varia-

Digitized by Google

tions, must be known if accurate speed control is expected from commercially standard apparatus.

There are some calls for more than 50 per cent speed reduction for special purposes. Ninety per cent by armature resistance may even be necessary. If 90 per cent of the line voltage is dropped in the resistance with a given current, it is evident that an increase of 11 per cent in current value will increase the resistance drop to full line voltage and leave nothing for counter voltage. If the current decreases 11 per cent the resistance drop falls to 80 per cent and the motor speeds up to double the desired speed. For such wide speed reductions by straight series resistance it is therefore necessary that the load be determined very accurately. These low speeds may be steadied by the use of a resistance in shunt to the armature. The effect of this is to make a portion of the current in the series resistance, and thus part of the voltage drop in the resistance, independent of the variations in motor current. The practical limit of this scheme is the amount of energy that may be wasted in the resistance. If the motor current in the armature is infinitely small compared to the line current, then its variation may be very wide with inappreciable change in resultant voltage at the motor terminals. A large wasted current is not only uneconomical but impractical. The armature shunt is only needed at low speeds, say below 25 per cent of normal. The next higher speed would be with straight series resistance. The load and desired speed determine the ohms at this point and thus set the maximum value of the total current. Greater currents would mean a bad jump in speed while lower currents give less steadying of the low speed. By the following formulæ the values of shunting resistance may easily be determined for any given set of conditions.

Let E = line volts.

E_a = volts counter e.m.f. of armature.

R = ohms series resistance. This is dictated by desired speed with series resistance only.

R_a = ohms armature and brushes. May be neglected where $E_a > 20$ per cent E. For lower values of E_a, R_a may be taken: 10 per cent E/I for 5 h.p., 5 per cent E/I for 50 h.p., 3 per cent E/I for 200 h.p.

I_a = armature amperes—if not known may be estimated.

Digitized by Google

R_s = ohms in shunt. This will usually be the unknown. Derived from given values of I_a, derived values of R, known values of E and R_a, and desired values of E_a.

I_s = current through armature shunt, R_s.

I_r = current through series resistance R.

E_s = voltage across armature shunt, R_s.

Then

$$I_r = \frac{E - E_a - I_a R_a}{R} \quad I_s = I_r - I_a, \; E_s = E_a + I_a R_a$$

and

$$R_s = \frac{E_s}{I_s}, \text{ or } R_s = \frac{R.E_a + R.I_a R_a}{E - E_a - I_a R_a - R.I_a}$$

NOTE:—For constant field strength the speed in per cent of normal will vary as the counter e.m.f. of the armature in per cent of the counter e.m.f. at normal speed. This counter e.m.f. or E_a at normal speed equals $E - I_a R_a$ or line volts less resistance drop in the armature. $I_a R_a$ for speeds above 20 per cent and for large motors may be ignored.

RESISTANCE MATERIAL

The limiting features in the resistance material, or resistor, appear in getting the current into the resistor and getting the heat out of it. The limits for various materials used as resistors are sometimes found from one factor and sometimes from the other. Consider in a general way the matter of getting current into a resistor. Since the resistor is specifically designed for the dissipation of heat, we should expect it to reach a fairly high temperature. While the resistor itself may be of a material which will stand high temperature without oxidation or deterioration of its surface, the material commonly used for connectors, or conductors to such resistors, is subject to deterioration at reasonably low temperatures. It is necessary therefore, that the terminals of the resistors be specially designed to hold down the temperatures at this point. A terminal attached to a hot resistor must necessarily heat considerably by conduction, and if to this conduction is added a considerable amount of internally generated heat, the temperature is apt to be abnormally high. A gradation of temperature is wanted between the lead wires and the resistor itself, and the temperature of the lead wire and terminal should be kept low enough to prevent the

Digitized by Google

melting of solder. One of the best examples of trouble with terminals is in the use of carbon resistances. Here the resistance of the contact is generally higher per unit of area than that of the resistor. Since the current is necessarily the same in resistor and terminal, this local increase in R means local heating and the use of carbon or graphite stick resistance which have many most excellent qualities has been limited by this terminal trouble. The same is true of water resistances. The highest resistance is ordinarily at the electrodes causing local heating.

How to get the heat out of the resistance is determined by a study of the laws of the flow of heat. The heat can be dissipated by radiation, by conduction, or by convection currents of fluids. All three methods are usually available to a greater or less extent. In the case of enclosed resistances it is almost entirely conduction from the wire to the exterior surface. In the majority of cases, the final disposition of the heat is into the air, the greater portion of this being by convection currents at ordinary temperatures, although at high temperatures, radiation plays a very important part.

Since practically all of the heat from a rheostat must be carried away by the air the actual design for a given limiting temperature both of issuing air and of rheostat exterior must be based on the laws of ventilation. The highest efficiency occurs when for a given amount of resistance material the quantity of air passed through the rheostat becomes a maximum. Vertical flues are more effective than horizontal baffles. The higher the temperature of the flue the more rapid the convective air currents and the greater the permissible watts for a given top area. What shall we take as a limit? Pieces of paper, wood, cloth, etc., begin to char at about 225 deg. cent., or 200 deg. rise above the usual room temperature. A 150 deg. cent. rise would then seem to be a safe point to choose for a limiting temperature. But this limit need only apply to the parts of the rheostat which may come in contact with external objects. With embedded rheostats this would mean the case. In the open type, the resistor itself would be measured. But where the resistor is provided with a frame and has screens to prevent the entrance of foreign combustible material into the enclosure, the temperature limit of 150 deg. rise should apply only to the *top* or hottest part of this frame. The interior heating surfaces or flues should be permitted say double this, or 300 deg. cent. rise. There would then still be a considerable factor for unforeseen overload before reaching a red heat, which occurs at from 500 to 600 deg. cent.

Digitized by Google

With these maximum limits established it then only remains to consider the resistor materials and the temperatures they may stand without deterioration. For alloys such as German silver this is the point at which the zinc distills off, changing its characteristics as a resistor. For alloys containing manganese, the distilling point of this metal is the limit. For wrought iron or iron wire, the limit is the temperature at which the resistor becomes plastic, which is close to that at which oxidation becomes bad. Cast iron can be run indefinitely at a dull red heat, with only very slow oxidation, but at white heat the oxidation is much more rapid, and the melting point is the final limit. For carbon or graphite, a bright red heat allows slow oxidation but without immediate deterioration.

While these are ultimate temperature limits, a factor of safety is desired and the limiting of the air temperature tends to hold temperature of resistor much lower. As a rough average of commercial structures with natural ventilation, the surface temperature of an open resistor, such as a cast iron grid will be about 350 deg. cent with the air issuing from top of frame at 175 deg. cent. The temperature of an imbedded resistor may be much higher than the surface of the enclosing material, and this temperature gradient from resistor to surface will vary greatly with the kind of material.

Probably the best way to bring out some of the limits of resistance material will be to consider specific forms. For very large currents used only for emergency, or tests, a water rheostat is admirably adapted. The boiling point of the water is the temperature limit, but terminal troubles are the main factor. It is comparatively easy to get the current into the electrodes, but the high resistance between the electrodes and liquid conductors, limits the current which can be carried per square inch of electrodes. This varies with the liquid, and also to some extent with the nature of the electrodes so that no specific figures can be given here.

For large currents one naturally turns to iron for a cheap and sturdy resistor. Old rails have been used in some specific instances, but here the trouble is mainly one of getting the current into the resistor itself. A 30-ft. 60-lb. rail has a resistance of 0.001 ohm approximately. When used for very intermittent service, such as starting a large motor, it will absorb 220 kw. for one minute with a temperature rise of approximately 100 deg. cent. to get 220 kw. into the rail with a resistance of 0.001

Digitized by Google

ohm, means the use of 15,000 amperes, and the shape of a 60-lb. rail does not readily lend itself to the attachment of 15,000 ampere terminals. For regulating duty its shape makes it inefficient.

The limit of temperature of wrought iron or steel resistors is the plastic stage. To prevent deformation under their own weight would require frequent insulating supports, making such structures expensive and generally reducing ventilation.

Cast iron as a resistance material is cheap, easily formed so as to give good arrangements for terminal attachments, easily adjusted in section to the desired resistance, and has an extremely narrow temperature range during which it is plastic. Ordinarily if the plastic temperature is reached, it will very quickly pass to the melting point and the grid instead of remaining in circuit, badly damaged will melt and open the circuit.

Cast grids reach the limit of heavy currents due to terminal features, while with low currents the limit is the ability to get sufficiently high resistance. By casting the grid with considerable mass of metal at the point of terminal connection, the generation of heat in the terminal due to its own resistance is reduced. The conducted heat from the hot section is dissipated from the large terminal surface at a low temperature. The terminals may also be placed out of the heated air flue and in a column of comparatively cool air. Manufacturing conditions limit the size of these terminal lugs, and since the current is carried from one grid to the other through the surfaces of these lugs, this current capacity between lugs becomes a limiting feature. In ordinary commercial practice this limiting feature coincides fairly well with the limits of current capacity of wires which are easily handled for attachment into such terminals. About 300,000 cir. mil stranded wire is as heavy as should be used. When carrying current continuously this means about 400 amperes, while when worked very intermittently, it may be used up to 1200 or 1500 amperes. This is the top limit that should be used on a single circuit, and greater currents should be divided on parallel circuits.

The resistance that can be obtained determines the low current limit of cast iron grids. A section 3/32 by $\frac{1}{8}$ in. by 8 in. long can be cast, but a long section, or several loops of this size will scarcely support its own weight, and must be supported. Cast iron varies a little in its specific resistance, castings from the same heat running about 500 ohms per cir. mil-ft. for heavy sec-

Digitized by Google

tions and a little higher, or about 550 ohms, for very thin sections. The thinnest practical section grid is commercially economical for continuous current dissipation, down to about 20 amperes but below that weight, space, and cost must be sacrificed.

Attempts have been made for years to find alloys of iron having a higher specific resistance, to extend the economical range of this construction below the 20-ampere limit. The high cost of these alloys has so far prevented their commercial adoption. Alloys of copper, nickle and other metals which have very high specific resistances are practically useless for this structure, because of their plastic stage being reached at comparatively low temperatures with the result that they distort under commercial operating conditions. The high cost of the alloy itself combined with the relatively low temperature at which it must be worked, makes other forms of supported material much more economical. While above 20 amperes continuous duty the cast grid has no serious rival, below 20 amperes some other form is necessary.

Space and weight consideration necessitate a resistor of high specific resistance. Iron wire meets this condition economically, but its high temperature coefficient and liability to rust, limit its field to fairly low temperatures. High resistance alloys are expensive and their commercial use requires that the weight be kept down to a minimum. More heat can be carried away from a wire by conduction through even poor heat conductors, than by convection of air and radiation, for a given temperature above the surrounding medium. This has led to covering such resistors with cement, enamel or mica, conducting the heat from the wire and distributing it over a larger surface from which it passes to the air with a lower surface temperature. Alloy resistance wires are generally plastic at comparatively low temperatures. This necessitates frequent points of support.

The limits of stiffness of resistor and its inherently small surface have led to a form consisting of a heat resisting insulating base, on which the wire is wound, and some heat resisting insulating covering attaching the wire to the base. The high current limit of such construction is primarily its cost, where cast iron grids can be economically used, coupled with difficulty of winding and clamping heavy resistor wires, and of bringing out suitable terminals. Unequal expansion of resistor and covering crack the latter if the wire is too heavy. There is no low current

Digitized by Google

limit to such constructions. The resistance that can be put into a given space is limited only by the size and specific resistance of the wire obtainable.

The temperature limit of such resistance units is much the same as for cast grids. For the same temperature of air, 175 deg. cent. approximately the same temperature of unit surface may exist, about 350 deg. cent. The actual temperature of the resistor will vary widely with the thickness and nature of the covering over it. Alloys are obtainable which will be stable up to even 1500 deg. cent. while the covering will generally deteriorate at red heat or a little above.

For continuous duty the order of limitations for such units is, first, temperature of issuing air, second, temperature of covering and third, melting point of the resistor. When used for intermittent or starting duty the order of the limits may be reversed. It takes some time to heat up the resistor covering to a point where it will give up heat to the air. The entire heat generated during a period of service may be absorbed by the unit and only gradually conducted to the exterior.

With a heavy covering of low heat conductivity the maximum surface temperature may not be reached till several minutes after current is cut off. This indicates a steep temperature gradient in the covering. If the rate of heat generation in the resistor is higher than conduction can carry it away, the temperature of the resistor must rise. Up to a certain point this rise in temperature seems to increase the rate of heat conduction and a balance is reached if given sufficient time. There appears however, to be a limiting rate of watt dissipation for a given wire, above which the resistor melts or vaporizes almost as soon as current is put on, acting very much like an enclosed fuse. When this action has occurred it is easily detected by examination of such a damaged unit. If gradually overloaded the resistor opens at the weakest point, and shows evidence of high heat on the covering. If suddenly overloaded to this limit the temperature rises so rapidly that the weakest spot does not have time to interrupt the circuit before several other spots have melted and opened the circuit, apparently simultaneously, yet without any evidence of overheating showing on the covering.

For momentary, intermittent or starting duty, the order of limits is therefore first the temperature of the resistor, second that of the covering and third that of the air.

Digitized by Google

Contact Limits

The limitations of contacts or switching parts are carrying capacity, and commutating capacity, the latter including ability to make, as well as break a circuit.

The carrying capacity of a contact cannot be defined accurately by a current density per unit of area of contact, but involves the material of the surfaces, the pressure per unit of area, and the mass and surface adjacent to the contact.

Of the commercially possible materials silver is probably best. It has a fairly high specific heat and good heat conduction, and the oxide is a good conductor. The latter is the main point, as the insulating oxide of other metals tends to reduce the area of contact.

Copper, brass and carbon follow in the order given.

While carbon has a relatively high specific resistance and high contact resistance it is used very extensively as a material for sliding contacts because of its freedom from welding, and its ability to withstand local high temperature without injury.

Laminated copper leaf brushes giving a well distributed pressure over the contact area are commercially best for large currents.

Contacts or switching devices in connection with rheostats must generally commutate current as well as carry it, and this feature limits the use of the various forms.

A sliding contact can make a circuit only through a leading point or line. Where this circuit parallels another circuit of relatively high resistance nearly the entire current passes through the line contact. This tends to heat the contact locally. If there is a good mass of heat-absorbing material closely adjacent to the line, the actual temperature rise may be small, but if there is little mass the line may quickly reach the fusing point. With copper or brass this may result in welding; with carbon it will cause burning.

These considerations lead to the limits of capacity of forms of contact. Round buttons make contact with the shoe practically at a point, and the curved shape reduces the adjacent mass. Segment forms make contact on a line, with larger masses adjacent. Knife blade contacts make one, or with very good fitting, two line contacts with small mass. The "butt" type approaches surface contact, and if of massive form has the mass adjacent to all parts of the surface. A butt contact with a light spring is no better than a sliding contact.

Digitized by Google

On making a circuit the current tending to heat the point of contact is determined by the resistance in circuit and the voltage. For the same current the heating is the same no matter what the voltage. On opening a circuit the voltage is the controlling factor. Below about 27 volts, no arc will form, and the heating ceases when the surfaces separate. Above this an arc tends to form, with heating and burning. If the contacts are cold and massive, and the current small the arc may not heat enough metal even locally to maintain itself. Either high voltage or high current, or to consider both, a high energy loss, tends to neutralize the effect of mass by heating the arcing point faster than it is cooled by conduction.

This is illustrated by the arcing distance of inductive circuits. On a test of the length of arc maintained when one or more magnetic switch circuits were opened, using heavy copper contacts, separated at slow speed, it was found that up to a certain current for any given voltage the arc would not hold 0.01 in. The smallest current that would arc this distance would often arc across a gap five times as large. Raising the current value would often run the arcing length up faster than the current. These values would have been materially changed for contacts of different weight and shape.

There are five factors that limit the amount of resistance than can be cut into circuit; first, the voltage, determined approximately by the current times the resistance of the step. Since there is generally some induction in a circuit, tending to maintain the current at its initial value, the value of the current existing before the introduction of the resistance must be used. Second, the value of the current. Third, nature of the contact, Fourth, the length of the gap. Fifth, the speed of operation.

Below 27 volts the length of the gap need not be considered, but the other factors all enter by reason of local heating on reduced surface of contact.

Above 27 volts, unless the currents are small compared to mass of contacts, gap length is important and becomes a definite limiting feature on sliding contacts which must bridge the gap. Filling the gap with insulating material to prevent the moving contact from falling between the fixed contacts, is dangerous as the arc drawn over the surface carbonizes the insulator, even if contact dust does not form a leakage path over its surface.

Step voltages therefore limit the use of sliding contacts.

Knife blade contacts may be used when handled quickly to

Digitized by Google

eliminate the effect of small surface and small mass. Butt contacts generally supply the mass element.

Applying these limits to types previously considered, we find that for field rheostats or dimmers, having relatively light contacts, small spacing, and slow or indefinite motions, stepping of resistance must be small to prevent arcing on cutting in resistance, and still smaller to prevent shunting too large a portion of the total current through a line contact when coming in or going off a contact.

On a motor speed regulator with sliding contacts and a device for holding the moving contact squarely on the fixed contact, coarser steps may be used as the local heating effect is eliminated. On a motor speed regulator having a switch form of contacts the steps may be as coarse as the switch will open.

On a motor starter with sliding contacts the steps may be coarser than on a regulator as the service is intermittent and heating effect reduced. The resistance is not normally cut into circuit slowly, so the arcing effect of the voltage per step may be neglected. When stopping a motor by a resistance starter the current in the starter is low by reason of the motor counter voltage nearly equalling line voltage.

In conclusion it may be well to state a few factors which will serve as short cuts to the consideration of sizes of rheostats. The maximum energy dissipation in an adjustable resistance in series with a fixed resistance across a given voltage occurs when the adjustable resistance in circuit is equal in value to the fixed resistance.

When the voltage over the rheostat varies as a result of changing its resistance, (as in a field regulator or dimmer) the series connection of steps makes the most efficient use of resistance material.

When the voltage over the rheostat however, does not change greatly with a change in its resistance, parallel connection of steps gives the best use both of resistor and of contact material. A load rheostat, which is used in series with an external resistance of negligible value, is an example of this. Here each step is arranged to pass a certain current, and at maximum load all resistance material is active.

Digitized by Google

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

ELECTRIC LINE OSCILLATIONS

BY G. FACCIOLI

In the summer of 1910 some tests were performed on the lines of the Great Western Power Company, which are operated at 100,000 volts, to obtain information on oscillations and rises of potential, due to switching operations. In these experiments the oscillograph was extensively used and this paper deals with some of the most important and representative records.

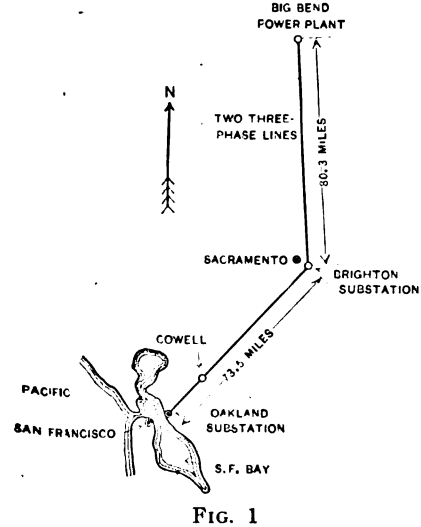


FIG. 1

Since it was necessary to conduct the investigation without interrupting the operation of the system, the study of switching phenomena is rather incomplete and limited to no-load conditions.

Mr. W. W. Lewis, who assisted in these experiments, gives a description of the methods and apparatus employed, in an appendix to this paper.

Fig. 1 is a map of the system of the Great Western Power Company. Two three-phase lines run on the same towers (Fig. 2) the conductors of each line being situated on a vertical plane. Each conductor consists of a copper cable No. 000, B. & S. gauge (seven strands, outside diameter $\frac{1}{2}$ in. approximately). The vertical

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

distance between conductors is ten feet, and the horizontal distance between lines is 14 ft.

The following tests were performed:

1. Switching in and out an open three-phase line at the generating station by high-tension switches.

2. Switching in and out an open three-phase line and step-up three phase transformer at the generating station by low-tension switches.

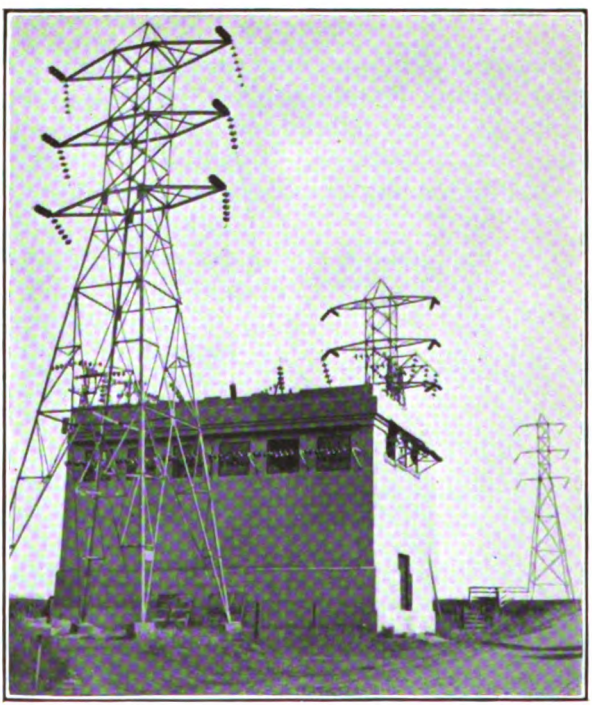


FIG. 2.—Transmission line of Great Western Pr. Co. at Brighton

3. Switching in and out a three-phase line, connected at the end to an unloaded three-phase step-down transformer, by high-tension switches, at the generating station.

4. Switching in and out a three-phase step-down transformer at the end of an unloaded three-phase line by high-tension switches.

5. Switching, by high-tension switches, one of the three-phase lines unloaded, on and off the end of the other three-phase line, carrying normal load.

Digitized by Google

Before entering into the discussion of the oscillographic records, it is advisable to study the constants of the line which, as we said before, consist of three No. 000 B. & S. copper cables situated on a vertical plane. The distance between conductors is 10 ft. and the length of the line is 154 miles.

Line Inductance. The total inductance of each conductor is 0.323 henry.

Line Capacity. The total capacity of each conductor to the neutral is figured as 2.2 microfarads. It is interesting to compare this figure obtained by calculation, with the figure derived from actual test.

From a series of experiments, which it is superfluous to enumerate, we find that when the voltage at the generator end of the line is 51,700 volts from conductor to neutral, the voltage at the far end of the open line is 64,000 volts from conductor to neutral. In this case, the charging current per phase is 48 amperes.

Assuming the capacity of the line concentrated in two identical condensers, one at the beginning of the line, and the other at the end of the line, we have

$$48 = 2\pi f c\,(51{,}700 + 64{,}000)$$

where f is the frequency, 60 cycles.

c is the capacity of each of the two condensers into which the line capacity was divided.

We find $c = 1.1$ microfarads.

This gives for the total line capacity from each conductor to neutral the value of 2.2 microfarads, which is identical to the value obtained by calculation.

Line Resistance. The ohmic resistance of each conductor is 50 ohms.

Generator Reactance. In all the experiments, the source of power is a 10,000 kv-a. three-phase generator. The windings of the generator are Y-connected, and the neutral is not grounded. The speed of the alternator is 400 rev. per min., its normal voltage is 11,000 volts. The machine has 18 poles and three slots per pole per phase.

In later calculations, we will frequently have occasion to use the value of the synchronous reactance, and of the leakage reactance of the generator.

The value of the synchronous reactance may be deduced by test, as follows:

Digitized by Google

Referring to Fig. 3, when the line is disconnected (high-tension switches open) the voltage of the generator is 4,430 volts between phase conductors.

When the line is connected (high-tension switches closed) the voltage of the generator for the same exciting current is 8,730 volts, and the current supplied by the generator is 400 amperes.

Neglecting the ohmic resistance and the exciting current of the step up transformer, we have

$$2\pi f L_g 400 = \frac{8730 - 4430}{1.73}$$

where L_g is the synchronous inductance per leg and f is the frequency, 60 cycles.

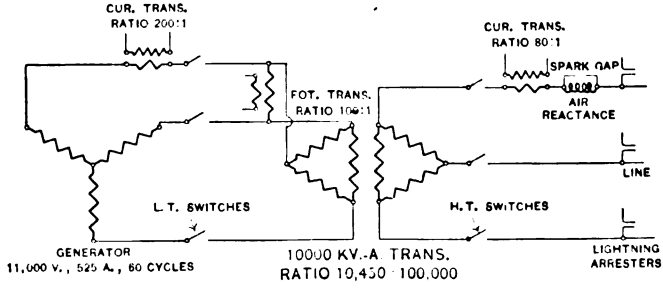


FIG. 3

$$L_g = 0.01645 \text{ henry}$$

If we refer the synchronous inductance to the high-tension side of the step-up transformer, whose ratio of transformation is 9.56, we obtain a value of $L_g = 1.52$ henry.

The leakage inductance of the generator deduced by calculation is 0.00276 henry, and referred to the high tension side of the step up transformer is 0.253 henry.

Transformer Reactance. The transformers used in all the tests—step-up or step-down transformers—are 10,000 kv-a. three-phase transformers, delta connected on both primary and secondary sides.

The leakage inductance of the transformer referred to its high tension side (L_t) is 0.088 henry, from each conductor to neutral.

Digitized by Google

Electrostatic Capacity of the Apparatus. The capacity of the generator windings, and of the transformer windings plays an important role in some of the oscillations, as we will see later. However, no attempt is made to determine the value of these capacities.

The theory of the phenomena involved in this investigation is well understood, and will, therefore, be omitted with the exception of a few instances. All the calculations and theoretical considerations in this paper had their origin or inspiration from Dr. Steinmetz's treatise on "Transient Electric Phenomena and Oscillations."

TEST No. 1

Fig. 3 shows the arrangement of the apparatus. The potential was recorded across one phase of the low-tension side of the step-up transformer.

The current was taken either across the secondary of the current transformer connected in the low-tension circuit, or across

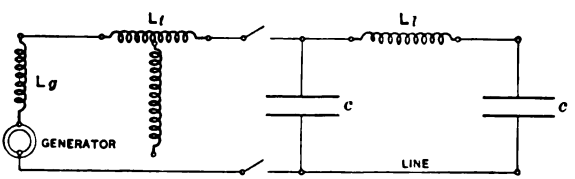


FIG. 4

the secondary of the current transformer connected in the high-tension circuit. All the switches in this and the following tests were of the oil type.

The low-tension switches were closed, and the generator and step-up transformer excited at a certain voltage. Then the 154 miles of three-phase line were switched in or out by means of the high-tension switches and the waves of e.m.f. and current were recorded at the moment of closing or opening the high tension switches.

The line under test was open at the far end.

Fig. 4 represents a simplified diagram of the connections.

L_g is the reactance of the generator.

L_t is the leakage reactance of the step-up transformer.

L_l is the reactance of the line.

c is one-half of the line capacity.

We neglect ohmic resistances and assume the susceptance of

Digitized by Google

the step up transformer equal to infinity. We neglect also the electrostatic capacity of the apparatus.

If, for a first approximation, we consider L_l as negligible, the closing and opening of the high-tension switches connects and disconnects the condenser given by the line capacity on and from the inductance of the generating system.

It is known that in a circuit consisting of a condenser in series with an inductance, the general expression of the e.m.f. across the condenser and of the current contains three terms.

The e.m.f. across the condenser is

$$e = e_1 + e_2 + e_3$$

And the current is

$$i = i_1 + i_2 + i_3$$

i_1 and e_1 are the values corresponding to stationary conditions of charging current and condenser potential at fundamental impressed frequency. The current leads the e.m.f. by 90 deg. and the effective value of the current is equal to the effective value of the e.m.f. divided by the line condensive reactance.

i_2 and e_2 represent a damped oscillation at a frequency independent of the impressed frequency but depending on the constants of the circuit, as follows:

$$\text{Frequency} = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \left(\frac{r}{2L}\right)^2}$$

Where L is the inductance of the circuit, C the capacity, and r the resistance.

This term depends mainly upon the point of the impressed e.m.f. at which the oscillation starts. There is no point at which this term is absent, and it reaches its maximum value when the oscillation starts at the maximum of the impressed e.m.f.

i_3 and e_3 depend on the constants of the circuit and upon the instantaneous values of current and of difference of potential in the circuit at the moment the oscillation starts.

A. Switching in Open Line by High-tension Switches

In the special case of switching in a line, if the operation is instantaneous and no secondary phenomena occur, the third term disappears since the e.m.f. and current in the line are zero at the moment the switches are closed.

Digitized by Google

The complex oscillation produced by closing the high-tension switches, thereby connecting suddenly the line condenser to the inductance of the generating system, will then consist in our case of a fundamental wave at 60 cycles on which is superimposed a damped oscillation whose frequency is—neglecting ohmic resistance—$f = \frac{1}{2\pi\sqrt{LC}}$.

Referring to Figs. 3 and 4, $L = L_g + L_t$ (line inductance neglected).

C = total line capacity.

For L_g we must take the value of the true self-inductance of the armature of the generator, and not the value of the synchronous inductance, as the latter includes the effect of armature reaction which must act on the field circuit where any change in flux is retarded by a change in field current.

If, however, the oscillation lasts a comparatively long time, then the armature reaction may enter in the phenomenon.

$L = 0.253 + 0.088 = 0.341$ henry.

$C = 2.2$ microfarads.

Frequency of oscillation = 139 cycles.

If L_t is not neglected and the circuit is treated as represented in Fig. 4, the frequency of oscillation is 167 cycles. Finally, by taking the total synchronous inductance of the generator in the circuit represented in Fig. 4, the frequency of oscillation is 83 cycles.

In these calculations we have ngelected the ohmic resistances, which are actually very low, so that they not only allow the occurrence of a free oscillation (r^2 less than $4L/C$) but do not practically affect the value of the frequency of oscillation.

This frequency is then comparatively low, and is between 83 and 167 cycles.

In Fig. 5, a 60-cycle wave is superimposed on a 120-cycle damped oscillation, and the resultant wave is almost identical to those obtained in the oscillograms, showing that the frequency of free oscillation found by test is of the same order of magnitude as calculated and approximately equal to 120 cycles.

However, the oscillograms show that closing the high-tension switches (Fig. 3) produces a more complicated phenomenon than theoretically assumed, as the switches do not close the circuit at once and permanently. Several secondary phenomena occur, as follows:

Digitized by Google

First: The three switches may not close the circuit at the same instant.

If one switch only closes its circuit, then one wire only of the three phase line is energized, and the potential of the system to ground is unbalanced (the system has no point permanently grounded). A charging current from this wire returns to the generator through the line capacity in series with the capacity to ground of the generating apparatus (transformer included) giving rise to a high frequency oscillation.

If two switches close and the third remains open, single-phase unbalanced load is thrown on the generator, giving rise to odd harmonics of the generated e.m.f. (third, fifth, etc.,) as shown clearly in some of the records.

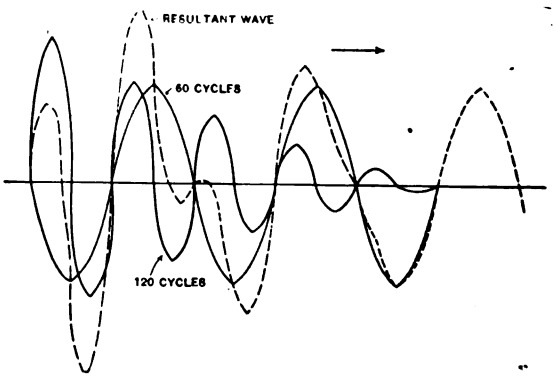


FIG. 5

Since the first closing of a high-tension switch is generally due to an arc before the metallic contact is established, it is natural to expect that the three switches of a three-phase system will not begin to close the circuit at the same instant.

Second. Arcs strike between contacts and die out before the metallic circuit is permanently established. It follows that instead of one starting oscillation, we obtain a series of oscillations, due to the successive closing and opening of the circuit.

We should then expect to find in the records a number of successive oscillations, which consist of a fundamental 60-cycle wave superimposed on a damped oscillation of 120 cycles, when all the three phases of the line are being connected to the generating system. Other frequencies will appear when the three phases are not connected simultaneously, and at the instant

Digitized by Google

when the line and the generating system become disconnected, the line on one side and the generating system on the other side will oscillate at their own natural frequency. Since the oscillograms of the electromotive force are taken on the low-tension side of the generating system, our records do not show the free oscillations of the line, and, likewise, do not show some of the oscillations which occur at high-frequency between the high-tension side of the transformer and the line and which do not go through the iron of the apparatus.

Record No. 1. Referring to Fig. 3, this record is taken at the moment of switching in 154 miles of unloaded three-phase line onto the high tension winding of the step-up transformer by closing the high-tension switches.

Before the switches are closed the wave of e.m.f. gives the generator e.m.f. (4,500 volts, 60 cycles), which shows the harmonic due to the teeth of the machine, while the current—taken in the high-tension circuit—is obviously zero.

After a high frequency impulse in the e.m.f. and current, due probably to an arc in one of the switches, the circuit is closed and the oscillation has the appearance of the resultant wave of Fig. 5 (120 cycles superimposed on 60 cycles).

The current has two long zeros before the metallic contact is permanently established, due to arcs in the switch, and finally the last oscillation occurs, which is damped in less than three fundamental cycles.

The new conditions of equilibrium are now reached, and the record shows an e.m.f. of 9,300 volts and a charging current of 48 amperes.

It must be remembered that the e.m.f. is taken across two conductors of the low-tension circuit, while the current is taken in one conductor of the high-tension circuit. Therefore, if the current leads the corresponding e.m.f. by 90 deg., the record should show the high-tension current leading the e.m.f. by 60 deg. or lagging 120 deg. behind the e.m.f. In many of the records either the current or the e.m.f. should be reversed to obtain the proper phase relation.

After the complex oscillation has occurred, the e.m.f. is smooth and does not contain the harmonic due to the teeth of the alternator, because of the very high impedance offered by the generator reactance to the flow of this harmonic (17th harmonic), which *lags*, the inductive reactance of the generator being several times the condensive reactance of the line at that frequency.

Digitized by Google

RECORD NO. 1

Digitized by Google

It is interesting to note that the first oscillation differs from the last in the wave of e.m.f. The first oscillation of e.m.f. shows a higher degree of distortion and contains odd harmonics (3rd and 5th) in addition to the natural frequency at which energy is exchanged between inductance and capacity. As pointed out above, this is due to the fact that all the three switches were closed at the last oscillation, while, very probably, all the three switches were not closed when the first oscillation started. Furthermore, while the first oscillation began with zero volts across the condenser, the successive oscillations started under different conditions. In fact, when the current is zero and the circuit is opened by the dying out of an arc in the switch, the e.m.f. across the condenser is near its maximum value and the energy thus stored in the line is dissipated at the natural frequency of the line, but this oscillation may not have died out entirely before the circuit is reëstablished. This introduces a third term in the expression of the e.m.f. and current, as mentioned above.

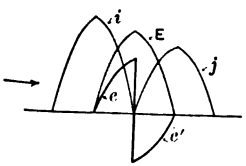


FIG. 6

The record shows also high frequency impulses in the e.m.f., due mainly to a change of energy from leading to lagging or vice versa. For instance, high frequency appears in the e.m.f. whenever the current goes to zero and the arc in the switch dies out. This occurs especially when the current maintains a low value for a comparatively long time due to the interference between the 60-cycle and the 120-cycle waves.

Referring to Fig. 6. Let us assume that the line is disconnected when the charging current, which is leading, is passing through zero.

At this instant the impressed e.m.f. E is maximum. On E is superimposed the e.m.f. e, which is generated by the flow of the charging current i through the reactance of the generating system, so that $E+e$ is active across the condenser. At the next instant the high tension current remains zero, because the arc in the high tension switch has died out, but the generator must excite the transformer, which is still connected. Hence, lagging energy is supplied, and a current j flows. The current j produces an e.m.f. e' across the reactance of the generating system.

It follows that a sudden change of difference of potential has occurred with the corresponding change of energy stored in

Digitized by Google

the capacity of the generating system. The new equilibrium is reached through an oscillation at the natural frequency of the apparatus.

This high-frequency appears in the e.m.f. of the low tension circuit and obviously not in the high tension current, but we must expect to find it in the low tension current, as we will see later.

The *switching-in* is then complicated by arcs and by the irregular closing of the three switches.

The record shows only the phenomena occurring in one particular conductor and phase, and does not show—as stated before—the free oscillations of the line. This line—154 miles long—oscillates at a frequency of 300 cycles when the length of the line corresponds to a quarter wave length.

The records also do not show, or show incompletely, what happens at the very first establishing of the circuit, as only the oscillations passing through the iron of the step-up transformer and of the measuring transformer are recorded. At the very first establishing of the circuit, the energy stored in the high-tension winding of the step-up transformer is thrown into the line, and a direct record of the high-tension e.m.f. would show this phenomenon and the process by which the potential is established on the line.

Finally, the records do not show what happens at the open end of the line, where the wave of e.m.f. undergoes a total deflection.

Record 1 gives as maximum over-tension 60 per cent above final maximum voltage. The current reaches a maximum of 160 per cent above final maximum value. The total complex oscillation lasts for a length of 10 fundamental cycles, or one-sixth of a second.

Record No. 2. This record is taken under the same conditions as the preceding record, but it gives the current in the low-tension circuit instead of the current in the high-tension circuit.

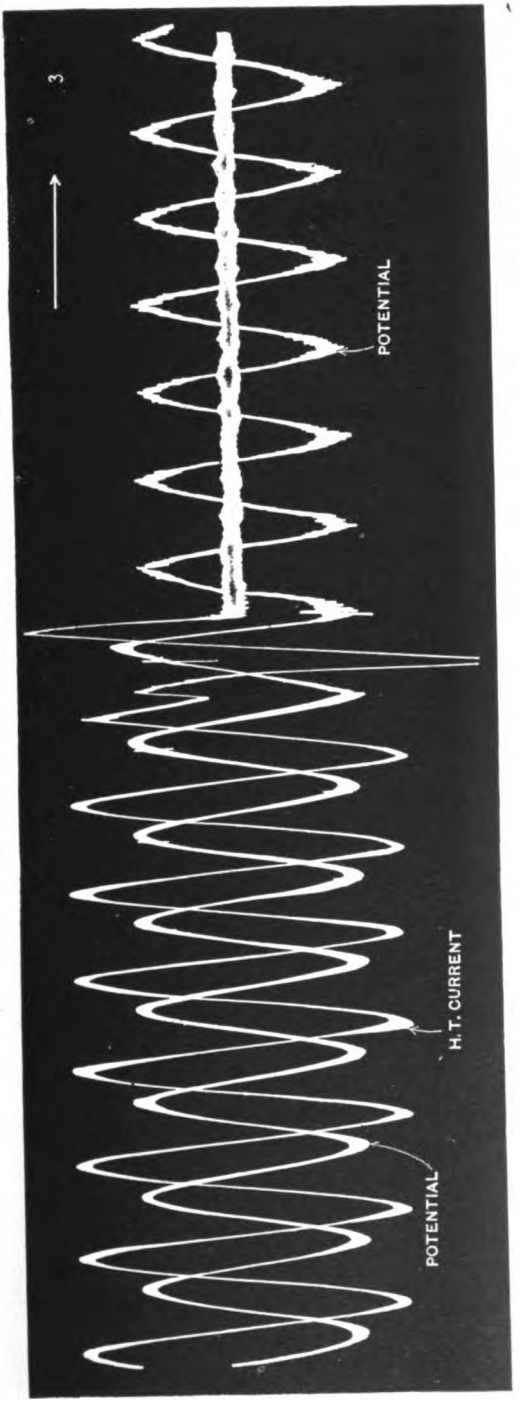
We start again with an e.m.f. of 4,500 volts and the exciting current of the transformer, which is so small that it does not show in the record. Then an oscillation similar to the one of Record 1 occurs, and finally we have 9,300 volts and 450 amperes.

All the remarks concerning the preceding record apply to this record, and the low-tension current shows, as expected, high frequency impulses when the arcs in the high-tension switches die out.

The maximum over-tension is 55 per cent above the final

Digitized by Google

RECORD NO. 2



RECORD NO. 3

Digitized by Google

maximum value, while the current reaches a maximum of 175 per cent above the final maximum value.

The complex oscillation lasts nine fundamental cycles, or three-twentieths of a second.

B. Switching off Open Line by High-tension Switches

Fig. 3 shows the connections used, and the records are taken at the moment of opening the high-tension switches, thereby disconnecting the line from the high-tension winding of the step-up transformer.

If the switching is instantaneous, then the sudden falling of the current I to zero gives an increase of potential E, such that $\frac{C E^2}{2} = \frac{L I^2}{2}$ where C is the capacity and L the inductance of the line. In other words, the electromagnetic energy stored in the system is transformed into electrostatic energy, and will be gradually dissipated.

Let us consider now the other limit case where the switch opens the circuit very gradually through a continuous arc, which increases slowly in length and resistance, so that the successive adjustments in value and phase of current and e.m.f. follow the progressive change in the conditions of the circuit. In this case, the disturbance is reduced to a minimum, but it is evident that the gradual modification of the circuit and of its constants occurs in the switch, where the most active consumption of the energy stored in the system takes place. It follows that, generally speaking, the opening of the circuit imposes severe conditions on the switch.

Between these two limit cases, approaching one or the other, according to the constants of the circuit and the characteristics of the switch, lies the actual opening of the circuit in practice.

The phenomenon is complicated, however, by the fact that the arc in the switch is apt to rupture and reëstablish itself several times before the circuit is permanently opened.

From this point of view we see that the phenomena and oscillations which accompany the opening of the circuit are very similar to those met with in closing the circuit. Two main differences exist, however. First, in opening the circuit the movable contact of the switch travels away from the other contact, while in closing the circuit, the movable contact travels toward the other contact.

In the latter case, then, the first arcs which strike are long,

Digitized by Google

and there may be long intervals between arcs, while there is little or no probability of rupturing small arcs near the end of the stroke. In the former case short arcs may die out at the zero points of the wave of current, but will be at once reëstablished owing to the short distance between contacts, while the striking of long arcs at the end of the stroke appears improbable when the movable contact is rapidly moving away from the fixed contact.

Second, in opening the circuit, if the interval between successive arcs is short, then the oscillation produced when the circuit is reëstablished finds the potential across the condenser very nearly equal to the impressed e.m.f. while in closing the circuit, at the first instant, the e.m.f. across the condenser is zero, and in the successive starting oscillations the difference between the impressed e.m.f. and the condenser e.m.f. may be considerable owing to the comparatively long time during which the circuit was left open.

Record No. 3. This record starts with an e.m.f. of 9,300 volts and 49 high-tension amperes.

The high-tension line is disconnected from the generating system through an oscillation which lasts four fundamental cycles, or one-fifteenth of a second, and then the e.m.f. falls to 4,500 volts and the high-tension current to zero amperes.

Before the oscillation of current begins the peaks of the waves of e.m.f. for five half-cycles show an almost instantaneous break apparently due to arcs which occur near the maximum value of the e.m.f. on the rising side.

This shows that the switch started to open the circuit $\frac{5}{2\times 60}$ = 1/24th of a second before the current in this particular conductor starts its oscillation.

Here again we note the absence of long zeros between arcs and the absence of high frequency impulses, except at the moment of final opening when the energy supplied by the generator changes from leading to lagging.

It is also remarkable that the wave of e.m.f. is hardly affected and that only a slight over-tension is produced, while the current reaches very high values. This oscillation of the current is similar to that obtained in closing the circuit and has the usual frequency of 120 cycles superimposed on the fundamental.

An inspection of the current wave shows, however, that the 120 cycles oscillating current does not start opposite in phase to

Digitized by Google

the fundamental current as seen in the previous records, but its starting zero is shifted 60 deg. from the zero of the fundamental, showing that this oscillation of current is started by an arc opening the circuit and re-closing it in one of the two switches other than that in series with the current transformer from which the record is taken.

This may explain also why the e.m.f., which is the e.m.f. of one phase of the delta, is not distorted.

We must remember, however, that the record gives the e.m.f. in the low-tension circuit and therefore does not show the phenomena which occur in the line and in the high-tension winding of the transformer, where the sudden change of conditions may produce high frequency impulses interesting the capacity of the line and the air reactance only of the high-tension winding of the transformer.

Record No. 4 is similar to record No. 3. It starts with 9400 volts and 450 low-tension amperes. After the line is disconnected the volts fall to 4400 and the current becomes the exciting current of the step-up transformer. In Record No. 4 the oscillation is limited again to the current and shows two successive arcs, the first, quickly reëstablished, in the switch in series with the current transformer, originating high frequency in the e.m.f.; the other probably in one of the other switches.

Here again the over-tension is small (30 per cent above normal maximum value), while the current reaches a very high maximum value. The total time of the oscillation is 3½ fundamental cycles, or a little more than one-twentieth of a second.

TEST No. 2

A. Switching in Open Line and Step-up Transformer by Low-tension Switches

Fig. 3 gives the diagram of connections.

The low-tension switches are left open and the generator excited to a certain voltage. The high-tension winding of the transformer is connected to the line (high-tension switches closed). The records are taken at the moment of closing the low-tension switches, thereby energizing step-up transformer and line.

The switching by low-tension switches differs from the switching by high-tension switches mainly in the following points: First, the switches are of the oil type but of different design. Second the energy must go through the transformer before reaching the line and therefore there will be no steep wave fronts

Digitized by Google

RECORD No. 4

RECORD No. 5

Digitized by Google

entering the line. Third, the magnetization of the transformer calls for an oscillation of magnetizing current depending on the point of the wave of e.m.f. at which the switching occurs. Generally speaking, if the switches are closed at the maximum of the wave of e.m.f. no rush of current will occur provided the residual magnetism is zero. If the switching occurs at the zero point of the e.m.f. then in the first half-cycle the induction in the iron must grow to twice the normal maximum value and a rush of current follows, etc.

These oscillations of magnetizing current will appear, of course, in the waves of low-tension current only.

Fourth, owing to the small voltage and the small distance between contacts the arcs in the low-tension switch are less severe and less frequent.

Substantially, however, the oscillations will present the same character as in the high-tension switching.

Record No. 5 gives the low-tension volts and high-tension amperes when the low-tension switches are closed. (Fig. 3).

For this record the potential transformer through which the wave of e.m.f. is taken is connected on the generator side of the low-tension switches (instead of on the line side as shown in Fig. 3). The record, therefore, starts with the no-load e.m.f. of the generator (4400 volts) and zero high-tension current.

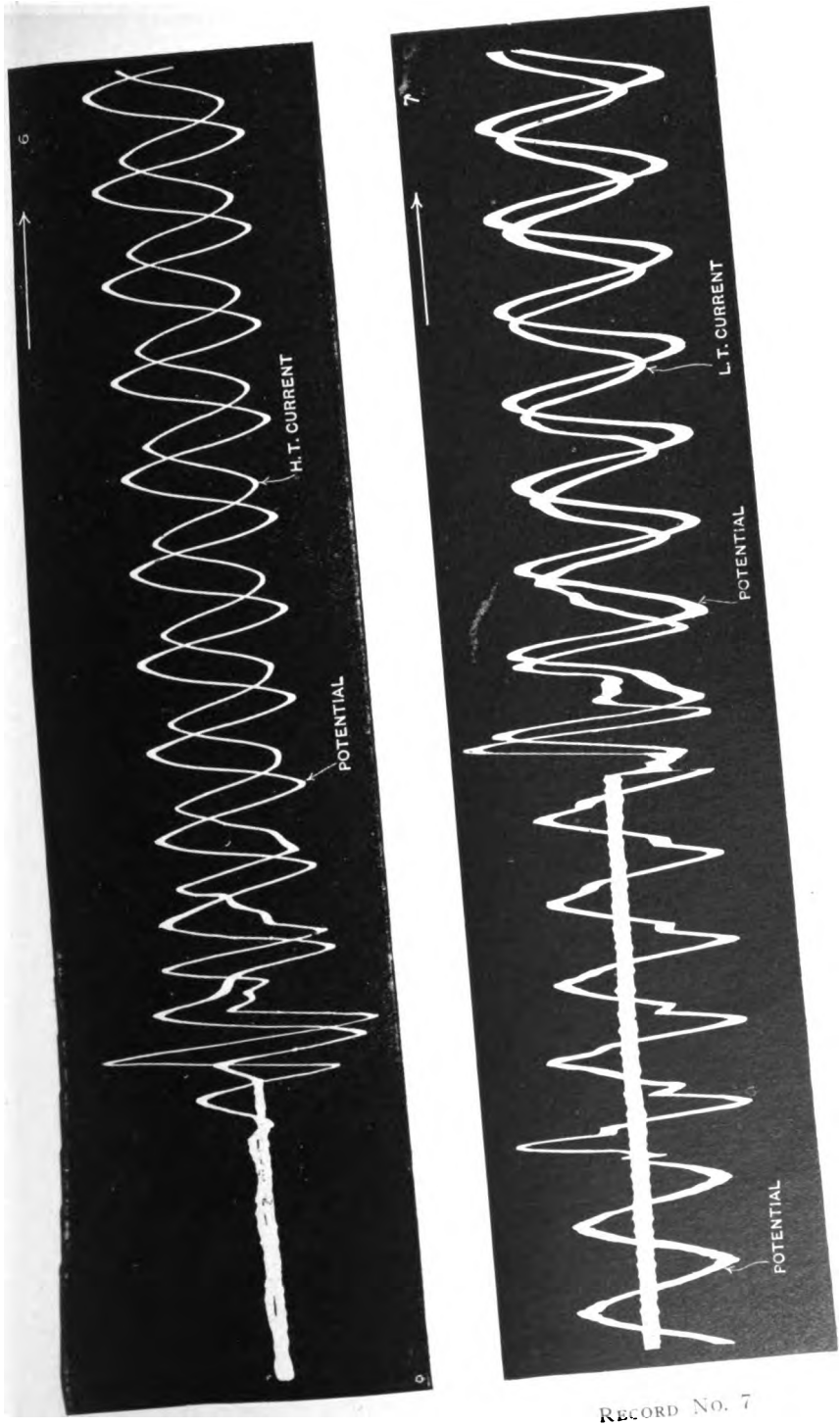
After the oscillation is completed, the e.m.f. is 9300 volts, and the high-tension current is 48 amperes. The conditions are therefore identical to those of Record 1. The maximum over-tension is 50 per cent above the final maximum value, and the current reaches a maximum value of 108 per cent higher than the final maximum value.

The oscillation lasts three fundamental cycles, or one-twentieth of a second.

The oscillation consists of two parts: First, a very short high frequency impulse in the e.m.f. due very likely to only one switch closing the circuit, then the usual oscillation of e.m.f. and current resulting from the 120 cycles damped wave superimposed on the fundamental.

It must be noted that in this case there is practically *one* fundamental oscillation, that is to say, the switches did not produce arcs which opened and closed the circuit several times before establishing permanent contact. As mentioned above, the oscillation of current due to the magnetization of the transformer does not show in this record, which gives high-tension current.

Digitized by Google



RECORD No. 6

RECORD No. 7

Digitized by Google

Another interesting point shown by the record is the rapidity with which the oscillation is damped.

Record No. 6. This is taken under conditions identical to those of Record 5. Since the potential transformer through which the wave of e.m.f. is taken is connected in this case on the line side of the switches this record starts with zero e.m.f. However, the idle line experimented upon runs parallel to the other three-phase line, which was carrying normal load during the test, and, therefore, the small e.m.f. due to the mutual induction between the two lines appears before the switches are closed.

The oscillation is very similar to that shown in the preceding record, and it is apparent that the switches did not close simultaneously, as the wave of e.m.f. starts ahead of the wave of current.

The maximum over-tension is 55 per cent above the final maximum value of the e.m.f. and the maximum value reached by the current is 165 per cent higher than the final maximum value of the current. The oscillation lasts $4\frac{1}{2}$ cycles, or a little less than one-fourteenth of a second.

Record No. 7 gives the low-tension e.m.f. and low-tension current under conditions similar to those of the two preceding records.

The potential transformer through which the wave of e.m.f. is taken is on the generator side of the switches, and the record starts with the no-load e.m.f. of the generator (4450 volts) and zero low-tension current.

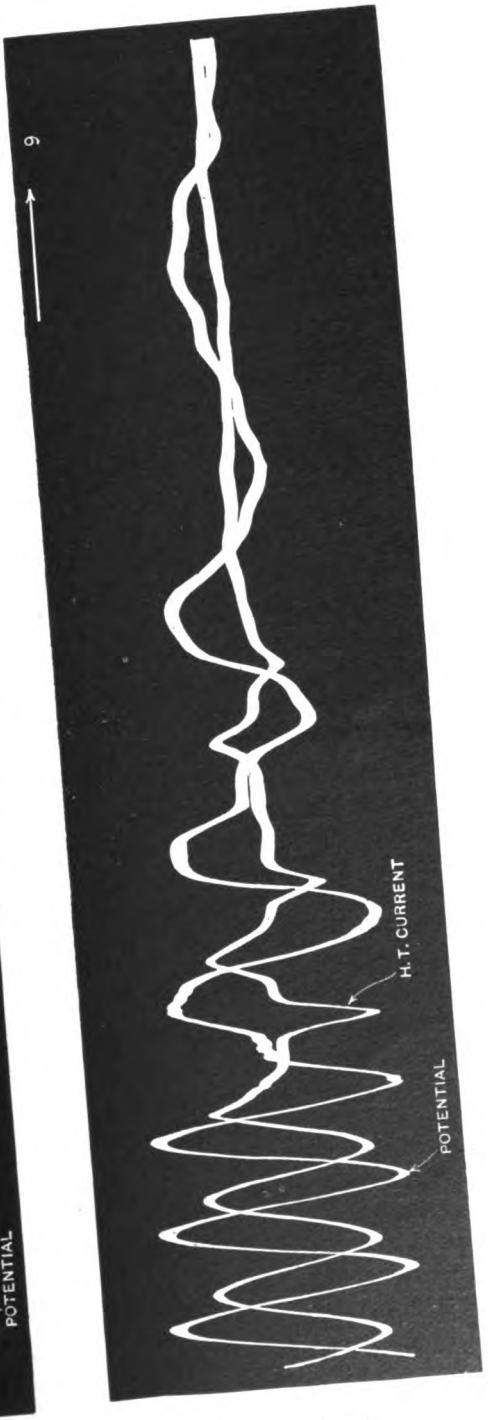
After the oscillation is completed, the e.m.f. is 9400 volts and the current is 450 amperes.

The maximum over-tension is 40 per cent above the final maximum value of the e.m.f. and the maximum value reached by the current is 125 per cent higher than the final maximum value of the current. The total oscillation lasts $8\frac{1}{2}$ fundamental cycles, or seven-fiftieths of a second.

This record shows clearly how the switches may not close the circuit at the same instant. In fact, before the current has started the e.m.f. is distorted for $4\frac{1}{2}$ cycles. This distortion of the e.m.f. shows the existence of a single-phase load, and the dissymmetry between the positive and negative waves of the e.m.f. reveal the presence of a considerable rush of magnetizing current. Then the third switch closes and the oscillation is similar to those obtained in the two previous records.

Digitized by Google

RECORD No. 8



RECORD No. 9

Digitized by Google

B. Switching off Open Line and Step-up Transformer by Low-tension Switches

Fig. 3 gives the diagram of connections. The generator excites the line through the step-up transformer, and the oscillation is recorded at the moment of opening the low-tension switches.

Record No. 8 gives the low-tension e.m.f. and low-tension current. It starts with 9300 volts and 450 amperes. After the oscillation is completed, the voltage and current fall to zero, since the potential transformer through which the wave of e.m.f. is taken is connected on the line side of the switch.

The maximum over-tension is 43 per cent above the normal maximum value of the e.m.f. and the maximum value reached by the current is 56 per cent higher than the normal maximum value.

The oscillation lasts a comparatively long time and is not completed in the record.

After the secondary current has entirely died out and the low-tension switches have disconnected permanently the transformer and line from the generating system, the e.m.f. across the secondary winding of the transformer still continues and reaches the zero value through a long, slow oscillation.

When the low-tension switches are entirely open, the high-tension winding of the transformer is still connected to the line and the presence of the e.m.f. on the low-tension side of the transformer is explained by an exchange of energy between the capacity of the line and the open-circuited inductance of the transformer.

Record No. 9 shows this very clearly. This record gives the low tension e.m.f. and high tension current under conditions similar to those of Record 8.

The record starts with 8650 volts and 44 amperes. In this case both current and e.m.f. do not rise above their normal maximum value. The oscillation lasts for 15 cycles, or one-quarter of a second.

After the secondary switches are opened the line and the transformer slowly synchronize. The high-tension current (which obviously has no image in the open secondary) consists of impulses having the characteristic shape of currents exciting iron circuits, and shows a strong decrement due to losses. The frequency of oscillation is very low, as the oscillating circuit is composed of the line capacity and of the total open-circuited

Digitized by Google

inductance of the transformer. The frequency also decreases gradually because the e.m.f. and flux density decrease and therefore the inductance of the transformer increases, lowering the frequency.

TEST No. 3

A. SWITCHING IN BY HIGH-TENSION SWITCHES UNLOADED LINE CONNECTED AT THE FAR END TO STEP-DOWN TRANSFORMERS

Fig. 7 is the diagram of connections used in this test. The end of the line is connected to an unloaded 10,000 kv-a. step-down transformer, delta-connected on both primary and secondary sides.

The generator excites the step-up transformer and the oscillation is recorded at the moment of closing the high-tension switches at the power house.

This test is similar to test 1-A, with the difference that the

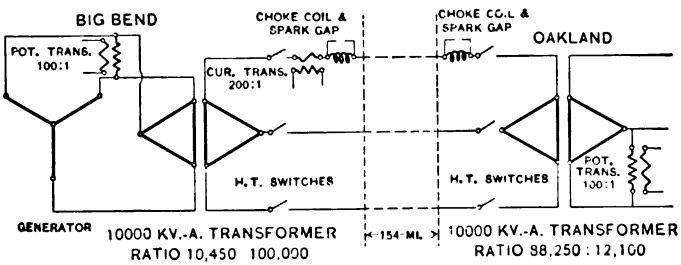


FIG. 7

three-phase line is not open at the far end, but closed by an unloaded three-phase step-down transformer.

Fig. 8 gives the equivalent circuits corresponding to the connections of Fig. 7. If we compare Fig. 8 with Fig. 4, we find that in the case of Fig. 4 the oscillations occur between the line capacity (neglecting line inductance) and the inductance of the generating system, while in the case of Fig. 8 the oscillations occur between the same line capacity and the inductance of the generating system connected in parallel to the open-circuit inductance of the step-down transformer. Since this open-circuit inductance of the transformer is exceedingly high in comparison with the inductance of the generating system, we conclude that the frequency of oscillation and in general all the phenomena met with in Test 1-A will be reproduced in Test 3-A. The switches used in both tests are the same.

Digitized by Google

Record No. 10 gives the low-tension e.m.f. and high-tension current when the high-tension switches connect the unloaded line and step-down transformer to the generating system.

The record starts with 4400 volts and zero current. After the oscillation is completed, the volts are 8700 and the high-tension current 43 amperes.

This record shows all the features pointed out in Test 1-A, namely, irregular closing of the switches, long zero of current, e.m.f. distorted by single-phase load, and oscillations due to a damped 120 cycles wave superimposed on the fundamental.

A new feature, however, which was not given by Record 1, is the distortion of the line current due to the magnetization of the step-down transformer. The line current assumes regular form after approximately 20 cycles following the completion of the main oscillation.

The maximum over-tension is 50 per cent above the final maximum value of the e.m.f. and the maximum value of the

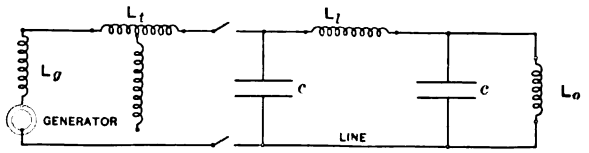


FIG. 8

current is 200 per cent higher then the final maximum value of the current.

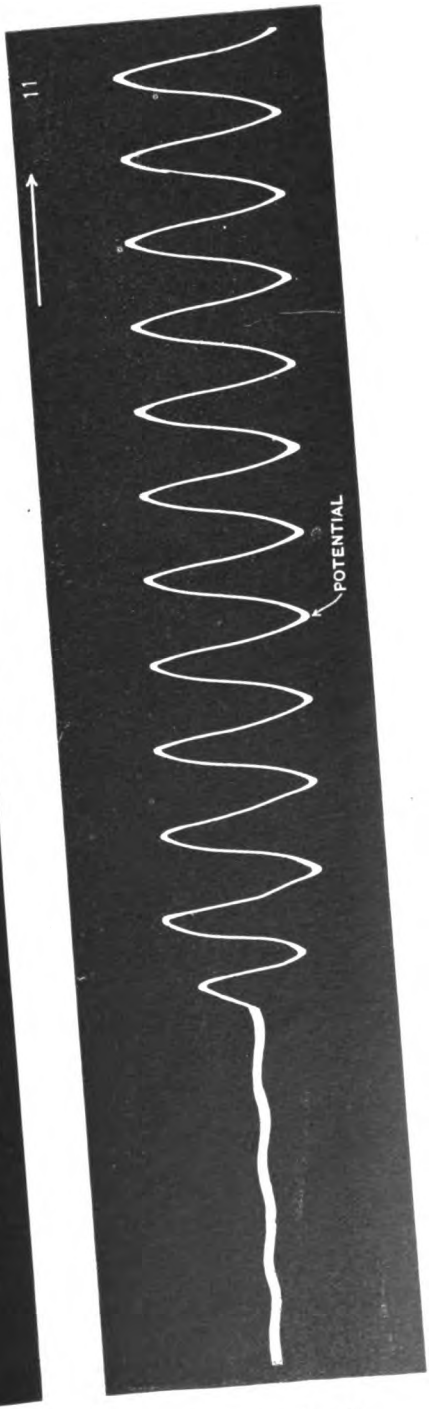
The total oscillation (disregarding the distortion due to the magnetization of the step-down transformer) lasts about 8 cycles, or a little less than fourteen-hundredths of a second.

In conclusion, the phenomena are substantially the same whether the line is open or closed on an unloaded transformer.

Record No. 11 is taken across one of the low-tension windings of the step-down transformer and shows the establishing of the electromotive force on the low-tension side when the high-tension switches are closed at the power house 154 miles away. The record starts showing a small e.m.f., due to the mutual inductance on the line under experiment from the parallel loaded line, and the final voltage is 12,000 volts. This corresponds to a voltage of 87,500 volts on the high-tension side of the step-down transformer, while the voltage on the high-

Digitized by Google

RECORD No. 10



RECORD No. 11

Digitized by Google

tension side of the step-up transformer at the power house is 81,400 volts. Of course, the record does not show what occurs on the high tension side of the step-down transformer, where the incoming wave of electromotive force is partially reflected.

B. Switching Out by High-tension Switches Unloaded Line Connected at the Far End to Step-down Transformer

Fig. 7 gives the diagram of connections used in this test. The oscillation is recorded at the moment of opening the high tension switches at the power house, thereby disconnecting the line and step-down transformer from the generating system.

This test is similar to Test 1-B, with the difference that the three-phase line is not open at the far end, but connected to a step-down transformer.

Record No. 12 gives the low-tension electromotive force and the high-tension current at the moment of opening the high-tension switches (see Fig. 7).

The record starts with 8700 volts and 43 amperes. After the oscillation is completed, the current falls to zero and the e.m.f. becomes the no-load voltage of the generating system, 4400 volts.

All the considerations mentioned in connection with Tests 1-A, 1-B and 3-A apply to this case, since the high-tension switches are the same in the four experiments.

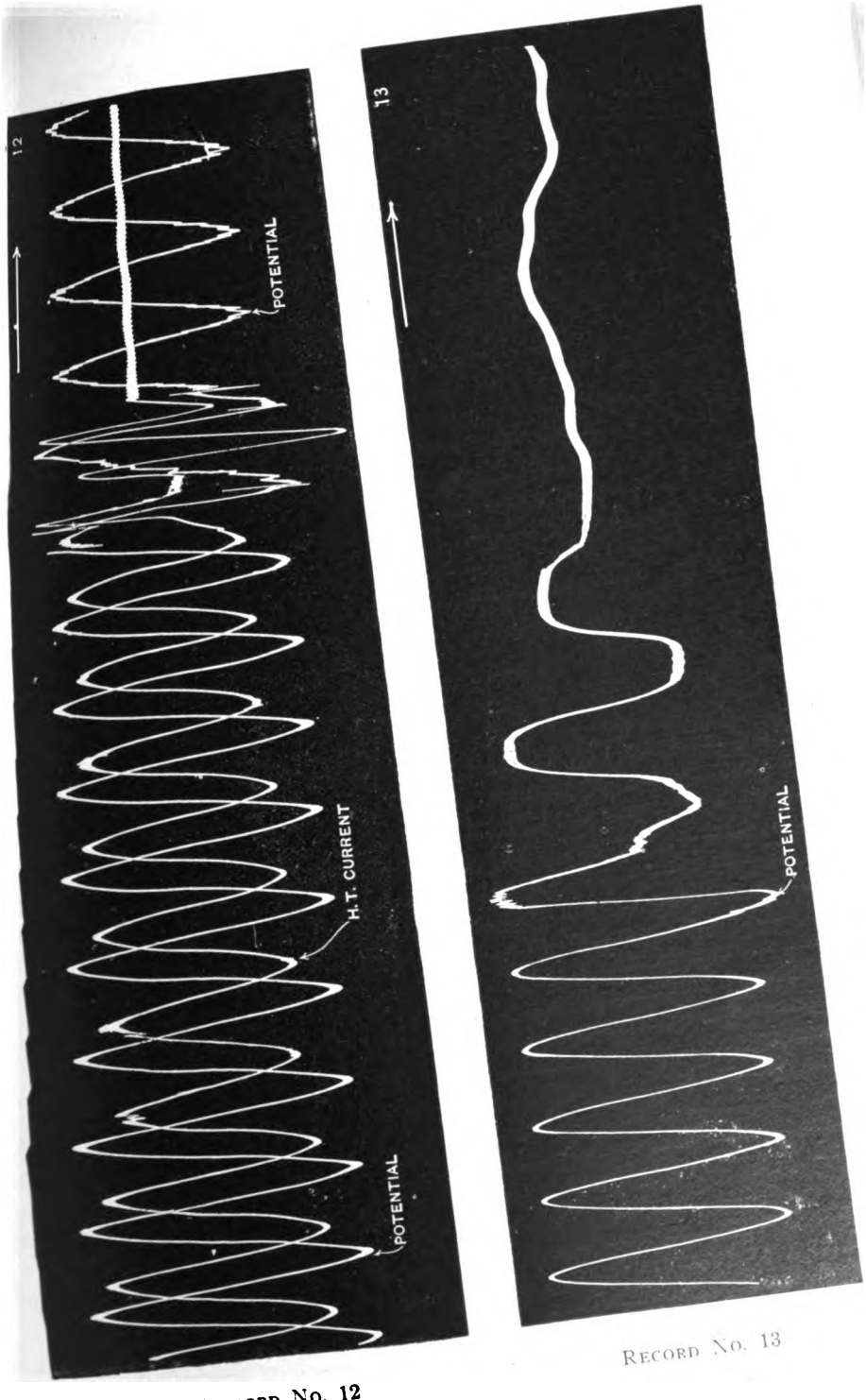
The wave of e.m.f. shows that an arc dies out and is immediately reëstablished in one of the switches, then—after less than half a cycle—a similar phenomenon is repeated, and the oscillation proper begins. At this moment the arcs in the switches are of such nature as to modify the conditions of the circuit, and the current shows the characteristic resultant wave due to a 120 cycle damped oscillation superimposed on the fundamental wave.

Here, again, the oscillation is damped very quickly, a considerable part of the energy being dissipated in the long arcs of the switches.

Record No. 13 is the complement of the preceding record, and gives the potential across one phase of the low-tension winding of the step-down transformer at the end of the line when the switches are opened at the power house under conditions similar to those of Record 12.

Record 13 starts with 12,000 volts, corresponding to 87,500 volts between line conductors at the receiving end of the line, the voltage at the power house being 81,400 volts.

Digitized by Google



RECORD No. 12

RECORD No. 13

Digitized by Google

Record 13 shows that the dying out of the electromotive force across the secondary of the step-down transformer consists of two distinct periods.

First, the high-tension switches at the power house are opening the circuit and modify the conditions of the circuit for the length of about one fundamental cycle. Second, the high-tension switches at the power house are permanently opened, and the typical low-frequency oscillation takes place between the capacity of the line and the open-circuited inductance of the step-down transformer, as in the case of Test 2-B.

In Record No. 12 the maximum over-tension is 20 per cent above the maximum value with line connected, and the current reaches a value 116 per cent higher than the maximum value of the charging current. The oscillation lasts three cycles, or one-twentieth of a second.

In Record No. 13 the maximum over-tension is 26 per cent above the maximum normal value.

TEST No .4

A. Switching in by High-tension Switches the Step-down Transformer (10,000 kv-a.) at the Receiving End of the Line

Referring to Fig. 7, the line is energized by the generator through the step-up transformer, and the records are taken at the moment of closing the high-tension switches at the far end of the line, thereby energizing the step-down transformer.

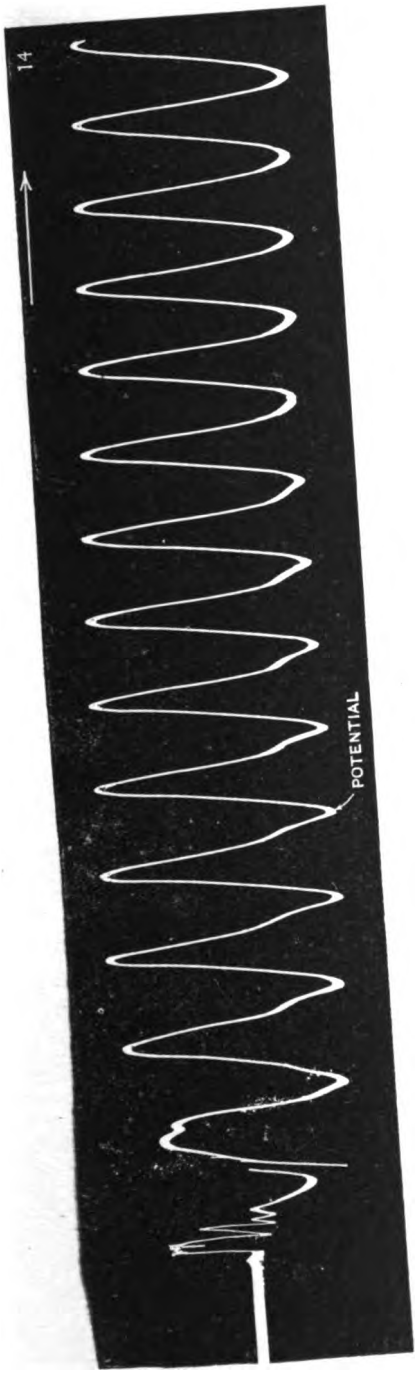
The high-tension oil type switches used in this test are different in design from the high-tension switches used in Tests 1 and 3.

However, the remarks made before on the irregular closing of the switches hold in this case also.

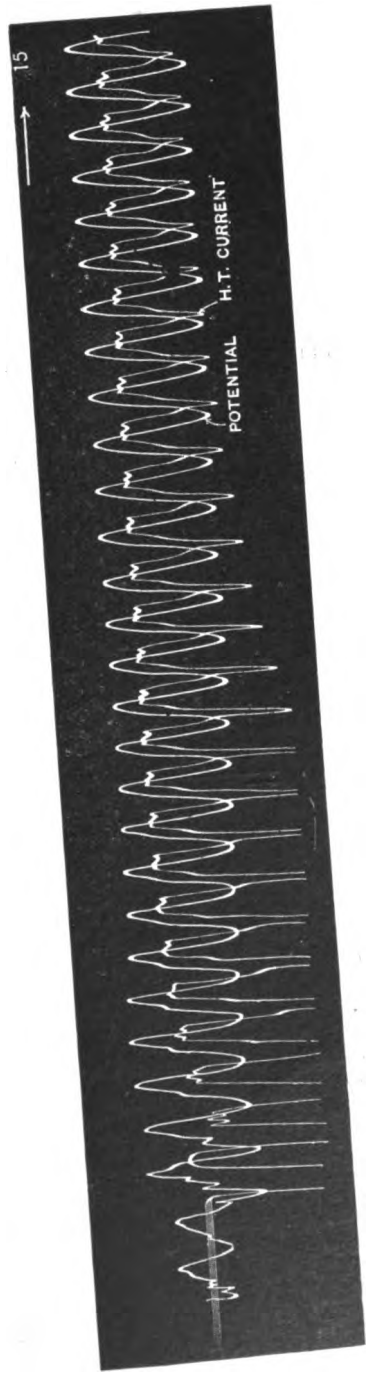
From a theoretical point of view, the most convenient way to picture the phenomenon consists, perhaps, in considering the winding of the transformer as a high-tension line, closed at the far end and under peculiar conditions of electrostatic capacity and inductance. Since the high-tension winding of this step-down transformer has a total length of approximately ten miles, this view of the phenomenon is plausible.

The records are taken on the low-tension side of the step-down transformer, therefore they reveal the establishing of the difference of potential across the low-tension windings, but fail to show the phenomena connected with the first instant of closing the circuit, when the line is, so to speak, drained by the high-tension winding of the transformer.

Digitized by Google



RECORD NO 14



RECORD NO. 15

Digitized by Google

Record No. 14 gives the low-tension e.m.f. across one phase of the low-tension delta of the step-down transformer (which is delta-connected on both primary and secondary sides.)

The record starts, obviously, with zero electromotive force, and after the oscillation is completed the e.m.f. is 12,000 volts, corresponding to 87,500 volts across line conductors.

Record 14 shows an oscillation consisting of three distinct periods: First, a difference of potential is established across the phase of the secondary winding under investigation, and this difference of potential falls to zero through an oscillation, due very probably to the striking of an arc in one of the switches only. Second, another switch closes the circuit, and a normal wave of e.m.f. of small value is established across the secondary winding. In this connection it must be noted that if two switches close the circuit, the full potential is applied at the terminals of the wind-

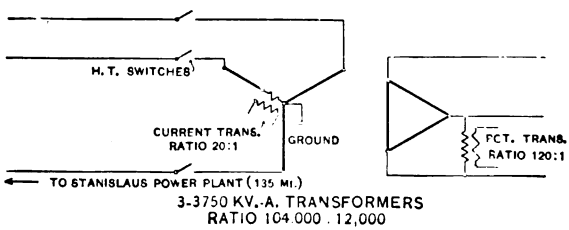


FIG. 9

ing connected across the two switches, while each of the other two windings of the delta receive one-half of the full difference of potential. This explains the low value of the e.m.f. in the second period of the oscillation. Third, all the three switches have closed the circuit, and the oscillation proper begins, showing an asymmetrical wave of e.m.f. due to the rush of current exciting the step-down transformer.

Record No. 15 shows these phenomena more clearly and gives the high-tension current as well as the low-tension e.m.f. at the moment of switching in the step-down transformers at the end of the line.

Record 15 was taken on the system of the Sierra & San Francisco Power Company, when three 3,750 kv-a. transformers, unloaded, were switched in at the end of 135 miles of three-phase line.

Fig. 9 gives the connections used in this case, the step-down

Digitized by Google

transformers being Y-connected, with grounded neutral, on the high-tension side, and delta-connected on the low-tension side.

The e.m.f. was taken across one phase of the low-tension delta and the current is the current flowing to ground through one of the high-tension windings.

Record 15 shows again the three periods in the oscillation of the e.m.f. and the rush of exciting current. The final voltage is 12,000 volts, corresponding to 104,000 volts across phase conductors.

The oscillation of e.m.f. in Record 14 lasts 10 cycles, or one-sixth of a second, and apparently no over-tension occurs.

A record of the generator e.m.f. and current taken at the power house at the moment of switching in the step-down transformer at the end of the line, under conditions described in connection with Record 14, shows no distortion whatever of the e.m.f. of the generator, but a distortion of the wave of current, due to the magnetization of the transformer.

B, Switching out by High-tension Switches the Step-down Transformer (10,000 kv-a.) at the Receiving End of the Line

Fig. 7 gives the connections used in this test.

The records are taken at the moment of opening the high-tension switches at the end of the line, thereby disconnecting the 10,000 kv-a. step-down transformer from the line.

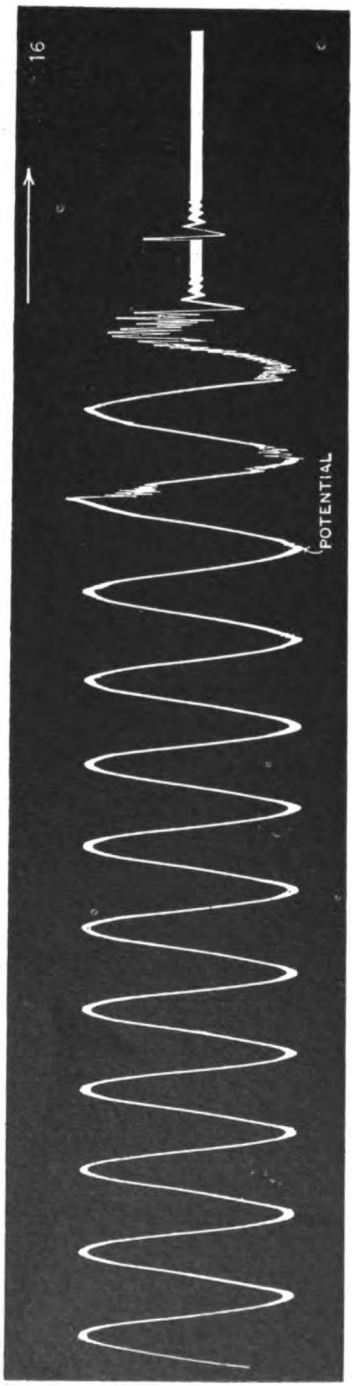
All the apparatus and connections are the same as those used in Test No. 4-A.

Record No. 16 gives the electromotive force across one phase of the secondary delta at the moment of opening the high-tension switches, which disconnect the step-down transformer from the line.

The record starts with an e.m.f. of 12,000 volts, corresponding to 87,500 volts across line conductors, and after the oscillation is completed the voltage is obviously zero. The main oscillation lasts 4 cycles, or one-fifteenth of a second, and the maximum over-tension is 20 per cent above the normal maximum value.

The most important frequency in this oscillation is the natural frequency of the transformer, which appears more and more prominent the more elastic and unstable is the connection between the transformer and the line, *i.e.*, when the switches begin to open the circuit their arcs are short and steady and the fundamental frequency applied to the transformer is but little

Digitized by Google



RECORD No. 16

RECORD No. 17

Digitized by Google

disturbed by the oscillation of the transformer. As the arcs become longer and the supply of energy to the transformer becomes more difficult, the natural frequency of the apparatus asserts itself more and more until, at the very end, the transformer is free to oscillate at its natural frequency. This natural frequency of the transformer is approximately 1700 cycles.

After the main oscillation is completed another short oscillation occurs, due probably to an arc in one of the switches. This last oscillation recalls in its character the beginning of the oscillation of Record 14, when the transformer was switched onto the line.

Record No. 17 is taken under identical conditions to Record No. 15, with the difference that the three step-down transformers (see Fig. 9) are switched off the end of the line of the Sierra & San Francisco Power Co. The apparatus, connections and conditions of Record 17 are identical with those of Record 15.

Record 17 confirms entirely the results obtained by Record 16.

A wave of generator e.m.f. and current taken at the power house at the moment of switching out the step-down transformer under the conditions of Record 16, does not show any distortion in the waves of current and e.m.f. of the generator.

TEST No. 5

A. Switching by High-tension Switches One of the Three-phase Lines, Unloaded and Connected at the Far End to a Step-down Transformer, onto the End of the Other Three-phase Line Carrying Normal Load

Fig. 10 gives the diagram of connections used in this test.

Line No. 2, excited by three 10,000-kv-a. three-phase alternators and three 10,000-kv-a. three-phase step-up transformers, carries a load of approximately 20,000 kilowatts, the majority of which is delivered at the end of the line—Oakland substation—154 miles away from the power house.

Line No. 1 is unloaded and connected at the power house to an idle 10,000 kv-a. step-down transformer.

Records are taken when the beginning of Line No. 1 is thrown at the Oakland substation by high-tension switches onto the high-tension bus bars, energized by Line No. 2. The high-tension switches are of the same type as those used in Test No. 4.

As stated before, the two lines are identical and run on the same towers for the whole length—154 miles. Therefore, when the high-tension switches are closed at the Oakland substation

Digitized by Google

the circuit consists of a loop 308 miles long, whose beginning and end are both at the power house.

Record No. 18 gives the electromotive force on the low-tension side of the generator end of the loop, and the electromotive force on the low-tension side of the step-down transformer at the receiving end of the loop. One of the electromotive forces is reversed in phase to avoid confusion.

It being necessary to maintain the load of Line No. 2 in operation and in consequence to avoid great variation in voltage, the voltage at the generator end of the loop was regulated by hand at the moment the switching occurred at the Oakland substation. The records, therefore, do not give the true oscillation in voltage and over-tension, which would have occurred if the fields of the generators had been kept constant.

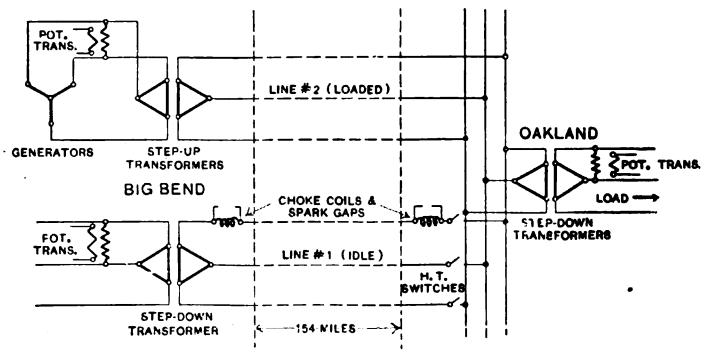


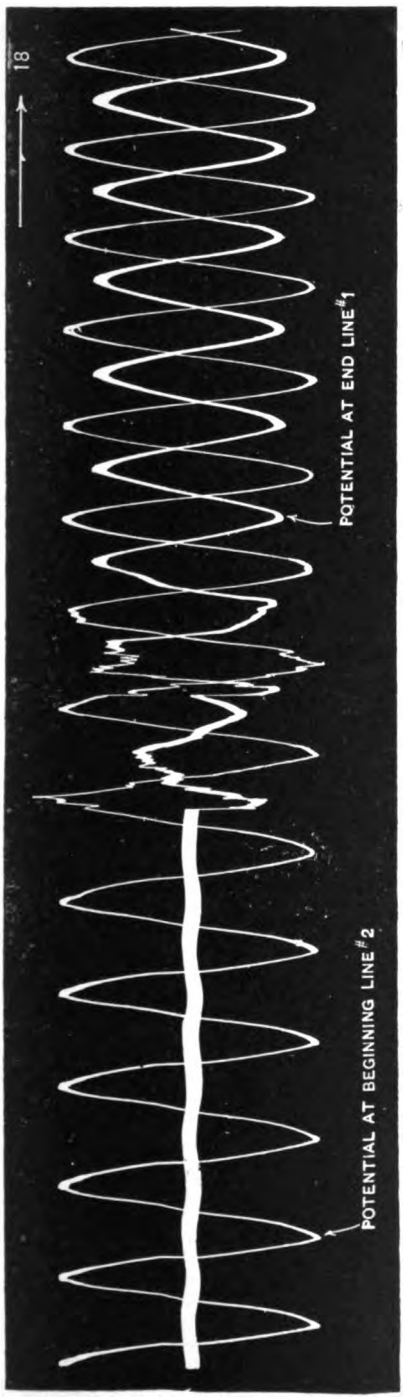
FIG. 10

When one line is connected to the other, the most prominent frequencies which appear are the full-wave oscillations of the total loop and of each line. Since the total loop is 308 miles long, its full-wave oscillation has a frequency of 600 cycles, while each line—154 miles long—has a full-wave oscillation of 1200 cycles, neglecting ohmic resistance.

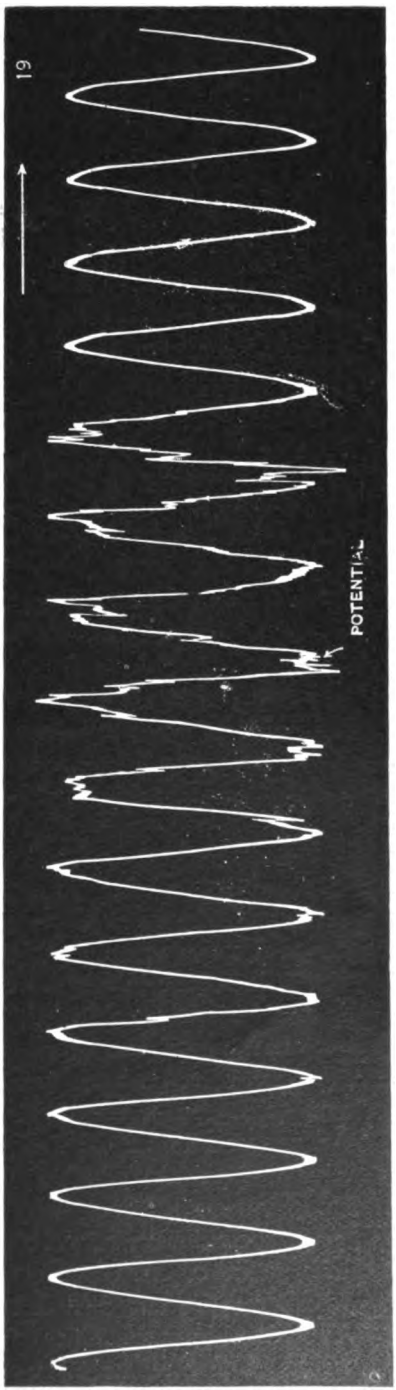
Record No. 18 starts with 11,100 volts at the generator end of Line No. 2 and zero volts at the receiving end of Line No. 1. After the oscillation is completed, the regulated voltage at the generator end of Line No. 2 is 11,225 volts, while the voltage at the receiving end of Line No. 1 is 9,850 volts.

These last voltages correspond to 107,500 volts between line conductors at the generator end of the loop and 94,300 volts between conductors at the receiving end of the loop.

Digitized by Google



RECORD NO. 18



RECORD NO. 19

Digitized by Google

All the remarks made before on the performance of high-tension switches apply, obviously, to this case and are not repeated.

The oscillation lasts 3 cycles, or one-twentieth of a second. The main frequency superimposed on the fundamental is approximately 1200 cycles.

Record No. 19 covers the same experiment as Record No. 18, but is taken at the switching point—the Oakland substation—on the low-tension side of the transformers carrying the load.

The record starts with a voltage of 11,300 volts and after the oscillation is completed, the voltage is 11,900 volts. This last voltage corresponds to 86,800 volts between line conductors at Oakland, while the voltage at the power house, at the generator end of the loop, is 105,200 volts.

The oscillation lasts nine cycles, or less than one-sixth of a second. A frequency of about 1200 cycles is superimposed on the fundamental.

No conclusion can be drawn as to the over-tension because the voltage was regulated at the power house, as explained above.

B. Switching by High-tension Switches one of the Three-phase Lines, Unloaded and Connected at the Far End to a Step-down Transformer off the End of the Other Three-phase Line Carrying Normal Load

Fig. 10 gives again the diagram of connections.

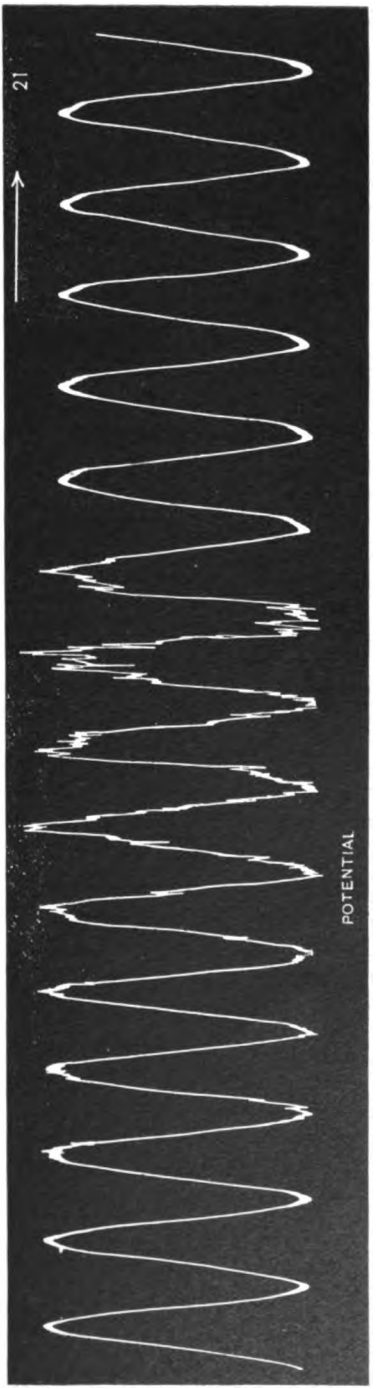
Record No. 20 is taken under conditions similar to those of Record 18, but it gives the low-tension voltages at the generator end and at the receiving end of the loop when the high-tension switches are opened at the Oakland substation and the idle Line No. 1 is disconnected from the loaded Line No. 2.

The record starts with 11,225 volts (107,500 volts between line conductors) at the generator end of the loop, and 9,850 volts (94,300 volts between line conductors) at the receiving end of the loop. After the oscillation is completed, the volts at the generator end of the loop are 11,100 (106,000 volts between line conductors) and the voltage at the receiving end of the loop is zero.

The oscillation of voltage at the beginning of the loop lasts six cycles, or one-tenth of a second. At the receiving end the oscillation is composed of two parts: The first part covers the period during which the high-tension switches are opening the circuit. The second part occurs after the switches are entirely opened and shows the characteristic exchange of energy be-

Digitized by Google

RECORD NO. 20



RECORD NO. 21

Digitized by Google

tween the disconnected line and the step-down transformer at low frequency.

The two parts of the oscillation over-lap, and a frequency of 600 cycles (half-wave length oscillation of 154 miles of line) is superimposed on the low frequency surge between line and transformer.

The first part of the oscillation shows a frequency of about 1200 cycles, increasing in magnitude and superimposed on the fundamental.

Record No. 21 covers the same experiment as Record No. 20, but is taken at the switching point—at the Oakland substation—and gives the voltage on the low-tension side of the transformers carrying the load.

The record starts with a potential of 11,900 (86,800 volts between line conductors) and ends with 11,300 volts (82,500 volts between line conductors).

Before the switches are opened, the voltage at the power house, at the generator end of the loop, is 102,500 volts.

The oscillation lasts eight cycles, or a little less than one-seventh of a second, and shows the usual frequency of about 1200 cycles superimposed on the fundamental.

In the last two records, at the moment of opening the high-tension switches the field of the energizing generators was strengthened in order to compensate for the drop in the line due to the disappearance of the charging current required by the idle Line No. 1. Under these conditions Record No. 20 shows a maximum over-tension of 22 per cent above the final maximum voltage of the loaded Line No. 2, and a maximum over-tension of 21 per cent above the final maximum voltage of the idle Line No. 1. In Record No. 21 the maximum over-tension is 27 per cent above the final maximum voltage.

These records, as repeatedly mentioned above, show only the potentials on the low-tension side of the step-up or step-down transformer, and in order to form an idea of the phenomena occurring on the high-tension line these tests were supplemented by measuring—at the instant of performing the different switching operations—the maximum sparking distance across a choke-coil inserted in series with a line conductor. Figs. 3, 7 and 10 show the exact location of the choke-coils shunted by spark gap.

Each choke-coil consists of 34 turns of half-inch copper rod. The inside diameter is $5\frac{1}{2}$ in., the outside diameter $6\frac{1}{2}$ in., the total height 32 in.

Digitized by Google

The inductance of each coil is 0.0326 millihenry, so that 100 amperes at 60 cycles would give across the choke-coil a drop of 1.26 volts.

Each of the different switching operations was repeated several times, and the following table gives the maximum sparking distances obtained across the coil.

Test No.	Diagram	Record No.	Sparking distances
1-A	3	1 and 2	½ in. at switching point.
1-B	3	3 and 4	¾ " " " "
2-A	3	5, 6 and 7	Less than ½ in.
2-B	3	8 and 9	Less than ½ in.
3-A	7	10	½ in. at generating station—switching point.
		11	Less than ½ in. at receiving end.
3-B	7	12	½ in. at generating station—switching point.
		13	Less than ½ in. at receiving end.
4-A	7	—	Less than ½ in. at generating station.
		14	1½ in. at receiving end—switching point.
4-B	7	—	Less than ½ in. at generating station.
		16	½ in. at receiving end—switching point.
5-A	10	18	Less than ½ in. at generating station.
		19	½ in. at switching point.
5-B	10	20	Less than ½ in. at generating station.
		21	½ in. at switching point.

These sparking distances represent the product of the intensity of the current times the steepness of its wave front. In Test 1-A, for instance, the maximum instantaneous value reached by the current is 130 amperes. A sine-wave current whose maximum value is 130 amperes would give across the choke-coil at 60 cycles a drop whose maximum value is 1.63 volts. In our test, the maximum difference of potential across the choke-coil rose to 5,500 volts, from which value we can form an idea of the steepness of the wave front. In the case of Test 4-A the difference of potential reached the value of 24,000 volts.

These results, supplemented by a general inspection of the records, allow us to draw the following conclusions:

In the class of phenomena which we have investigated, abnormally high potentials to ground or between line conductors, or across windings of apparatus, are not to be feared. The maximum over-tension which the records show is 60 per cent above normal operating value. This corroborates the theory of these phenomena, whereby the maximum possible over-tension is equal to the normal tension when the damping effects are neglected.

Digitized by Google

On the other hand, a glance at the records impresses one with the fact that, if high potential is absent, high frequency is a common occurrence. The spark gap tests tabulated above confirm this impression and point out the danger resulting to the end turns of apparatus from these switching operations.

It seems, therefore, that our common method of protecting transmission systems by lightning arresters connected in series with a spark gap does not answer the purpose effectively in all cases.

Of course, atmospheric disturbances, arcing grounds, switch-

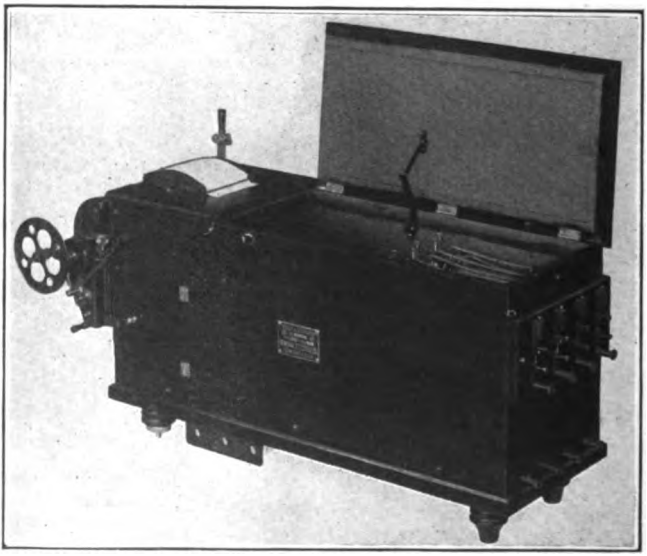


FIG. 11.—Oscillograph

ing heavy loads, etc., constitute a class of disturbances which may be taken care of by our present protecting system, since they may give origin to high differences of potential across conductors or to ground; but the switching phenomena with which this paper deals call mainly for protection against high frequency impulses, whose existence has been repeatedly shown by theoretical considerations, but perhaps has not been properly realized in practical operation.

The fact remains, however, that these tests were performed for a long period of time—several months—on systems operated

Digitized by Google

at the highest voltages in use to-day. The switching operations performed, for instance, on the system of the Great Western Power Company during this investigation were more numerous and more severe than the system will experience in a long time of normal operation, and yet no damage whatever resulted to the line or to the apparatus, showing that the confidence of the engineers in high-voltage installations is justified.

The only danger, perhaps, consists in the possibility that some of the frequencies, at which inductances and capacities exchange energy, will coincide with the frequency of the generating system or its harmonics. A simple calculation of the constants of the circuits is, however, sufficient to obtain the value of these frequencies and to ascertain the absence of resonance.

The high frequency impulses, which originate at the point where the switching is performed, extend over a short length of the circuit only. The steepness of such impulses is quickly reduced and smoothed over and their effect is localized.

The oil high-tension switches open the circuit, as generally admitted, at the zero point of the wave of current, and since the establishing of the circuit is generally due to an arc, they close the circuit at the maximum point of the wave of e.m.f. or in its neighborhood. No attempt was made in these experiments to close the switches at different points of the wave of e.m.f., but it was preferred to obtain information as to the point of the wave at which the switches would naturally close the circuit.

Low-tension switching is preferable—when possible—to high-tension switching. In this connection, it is interesting to note that high-tension switching may be undesirable when transformers are near the switching point, in which case low-tension switching may be generally arranged for.

In energizing a line two methods of procedure may be followed (*a*) the open line is connected to the generating system, and the step-down transformer is thrown onto the end of the live line: (*b*) the step down transformer is connected to the dead line and then line and transformer are connected to the generating system.

Our records show that the second method is the best, as it produces one oscillation only and this oscillation is of the same character as the less severe of the two oscillations which take place in the first procedure.

This paper discusses, naturally, only a small number of the numerous oscillograms taken. For each switching operation several records were obtained, and the ones published are representative.

Digitized by Google

APPENDIX

BY W. W. LEWIS

The method of recording the waves shown in the foregoing paper is described in this appendix.

Apparatus Used. The oscillograph used was of the three-element electromagnetic type illustrated in exterior view in Fig. 11 and previously described in papers before the Institute.

This is regularly equipped with the film holder, shown in Fig. 12*a* and 12*b*, which consists of three parts; a cylindrical drum to which the film is fastened, by means of spring-clips, a light-tight hollow semi-cylindrical holder in which the drum revolves, and a cover which fits over the end of the holder after the drum is in place. The holder is provided with a rectangular aperture and shutter, and a suitable arrangement for holding in place on the oscillograph.

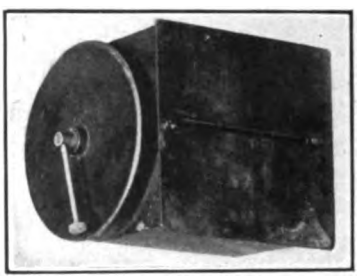


FIG. 12A.—Standard film holder

The standard film for which this holder is adapted is $3\frac{7}{8}$ in. wide by $12\frac{3}{4}$ in. long.

An auxiliary arrangement was devised for films longer than

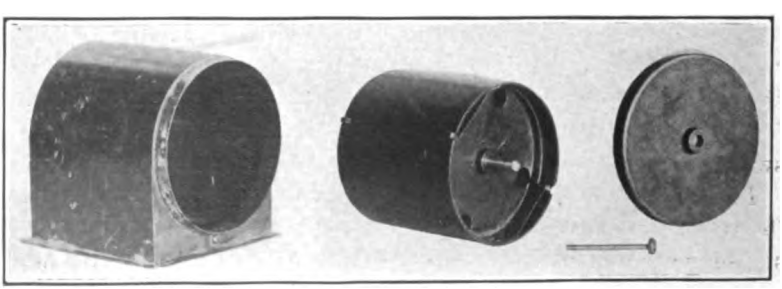


FIG. 12B.—Standard film holder

the standard. This is illustrated in Figs. 13*a* and 13*b*. The following modification in the regular holder was necessary. The clips for holding the regulation film to the drum were removed and a slot $\frac{1}{32}$ in. wide by 2 in. long cut in the drum parallel to its axis. An aperture was cut in the lower part of the holder

Digitized by Google

$\frac{3}{4}$ in. wide by $3\frac{7}{8}$ in. long. A small wooden box with open top and inside dimensions $1\frac{1}{2}$ in. by $3\frac{3}{4}$ in. was made. This fitted over dowel pins and was fastened to the holder by small hooks. The box was made for a No. 2 Bull's Eye Kodak spool, as this was a convenient size and permitted of ready means of holding in place. These spools have a hole bored throughout their length, and a brass rod with a knurled head served to hold them in place and forms an axis on which they could revolve. A piece of spring brass pressed a small brass cylinder, through a hole in the side of the box, against the end of the spool and served to act as a brake. This was later found to be unnecessary.

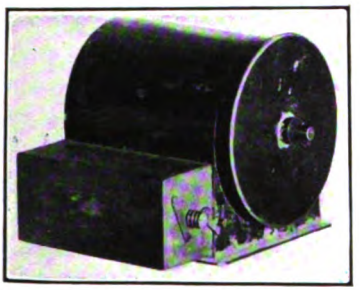


FIG. 13A.—Film holder with attachment for long films

Method of Operation. The method of operation with the regulation film will first be described, assuming that all the preliminary steps have been taken and there remains only the exposure of the film. The procedure in making the exposure is

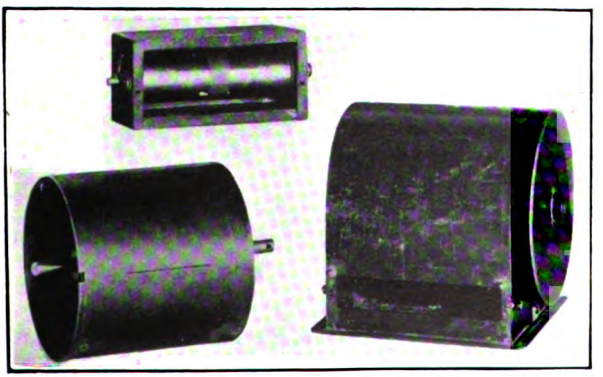


FIG. 13B.—Film holder with attachment for long films

ordinarily as follows: First, start motor which revolves the film; second, open aperture in the film holder; third, operate electromagnetic shutter.

The oscillograph shutter may be operated in two different ways, first by a worm contact, which opens the shutter and

Digitized by Google

commences the exposure at the beginning of the film, stopping the exposure at the end of one revolution; after the lever is pulled the film holder makes about one revolution before the shutter opens. Second, by the instantaneous or disk contact, which opens the shutter instantaneously when the releasing lever is pulled and keeps it open during one revolution of the film.

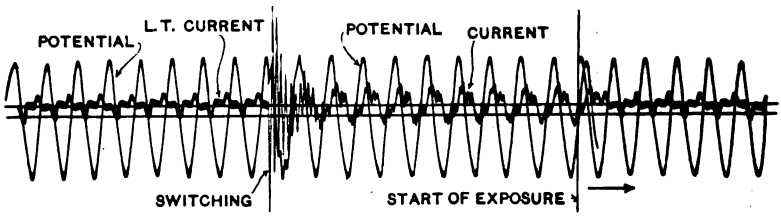


FIG. 14

For ordinary normal waves of 60 cycles frequency the film is revolved at the rate of 600 rev. per min. In recording the oscillations, however, this speed was reduced to 200 rev. per min. That is, the $12\frac{7}{8}$-in. film passed the light aperture in three-tenths of a second. At this rate of speed 18 cycles of a 60-cycle wave could be recorded. This, in most cases of switching, would be ample to record the complete oscillation, providing the ex-

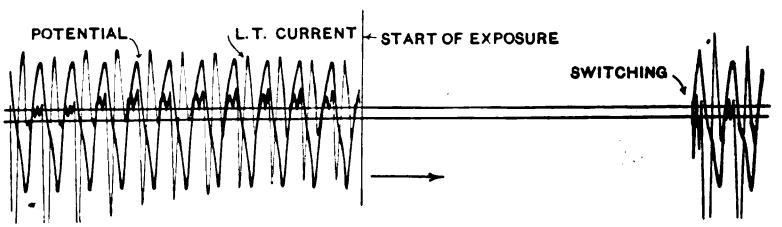


FIG. 15

posure of the film could be so timed that the oscillation commenced sufficiently near the beginning of the film.

The first method of operating the shutter, that is, by the worm contact requires that the shutter lever be operated a trifle more than three-tenths of a second before the oscillation commences; the second method requires that the shutter lever be operated only in time to make sure that it is open before the

Digitized by Google

oscillation takes place, probably one one-hundredth of a second before the oscillation begins, and it has the disadvantage that the exposure may begin at any point on the film.

The second method was found to be the most suitable and some excellent results were obtained. For example see Fig. 14, which shows the complete record. Here the exposure commenced about one-fourth the film length from the end, ran off the end, commenced again at the beginning of the film and ran along to the starting point. The oscillation took place about one-third of the length from the beginning of the film or about one-sixth of a second after the shutter opened. Fig. 15 shows a record that is not satisfactory. The exposure began about the middle of the film. The oscillation commenced nearly at the end of the film and had not been completed when the starting point was again reached. Other records were obtained in which

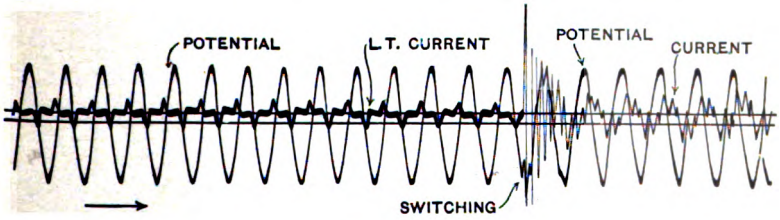


FIG. 16

the exposure commenced at the beginning of the film and the oscillation was wholly completed within the length of the film, Fig. 16 shows one of these.

It will be readily appreciated that this required very accurate timing. Automatic timing devices were tried, but were found to be unduly complicated, in view of the nature of the power plant wiring and switching; and especially so when the switching was done in one station and the oscillograph located in another.

To overcome the shortcomings of the regular film and insure more certain results, the arrangement for long films was devised. This arrangement immediately extended the usefulness and accuracy of the apparatus. The films used were $3\frac{1}{2}$ in. wide by 48 in. long, so that instead of three-tenths of a second in which to make the exposure, about 1.1 seconds were now available, and approximately 66 cycles could be recorded; the exposure always commencing at the beginning of the film.

Digitized by Google

The procedure in loading these films is as follows: They are loaded in daylight as with an ordinary roll film camera, the film being placed in the box and the end of the black paper covering drawn through the aperture in the holder and inserted in the slot in the drum (see Fig. 17). About one-half turn is made around the drum with the black paper and the box drawn up and fastened to the holder.

The routine in exposing the standard or short films was to first start the motor that revolved the film, next open the aperture in the film holders and lastly to operate the electromagnetic shutter at the proper instant. With the long films the routine was in the reverse order, that is, to first open the light shutter and keep it open, next open the aperture in the film holder, the black paper protecting the film from exposure, and finally at the

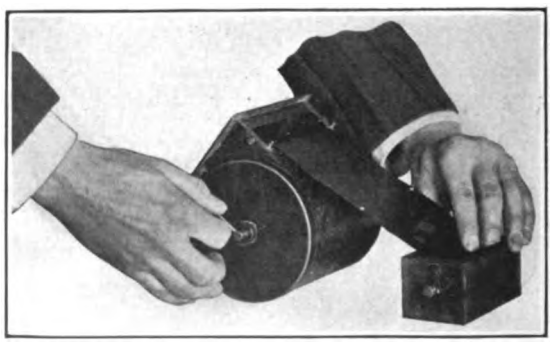


FIG. 17.—Showing method of loading a long film

proper instant to start the motor and wind the film from the spool onto the drum.

The motor was operated at high speed and the reduced speed required by the film secured by means of counter-shafting, which is clearly shown in Fig. 18. The belts, which consisted of heavy twine, were made very tight. By this means acceleration was secured in probably one-fiftieth of a second, or practically instantaneously. The film was preceded by 20 in. of black paper of which about one-third had already been wrapped around the drum, leaving two-thirds, or one turn, to be wound around the drum before the film could be exposed. This allowed about three-tenths of a second to elapse between the starting of the motor and the exposure of the film, giving a wide factor of safety for acceleration.

Digitized by Google

As familiarity was gained with this device, the efficiency of operation was increased from probably 50 per cent with the short films to approximately 95 per cent with the long ones. At one particular station where fifteen exposures were made, all were successful—an efficiency of 100 per cent.

The significance of this can be appreciated when it is stated that all the signals were manual and vocal. When the switching was done in the station where the oscillograph was located, the signal passed from the oscillograph operator to the switchboard attendant either direct or through an intermediate person.

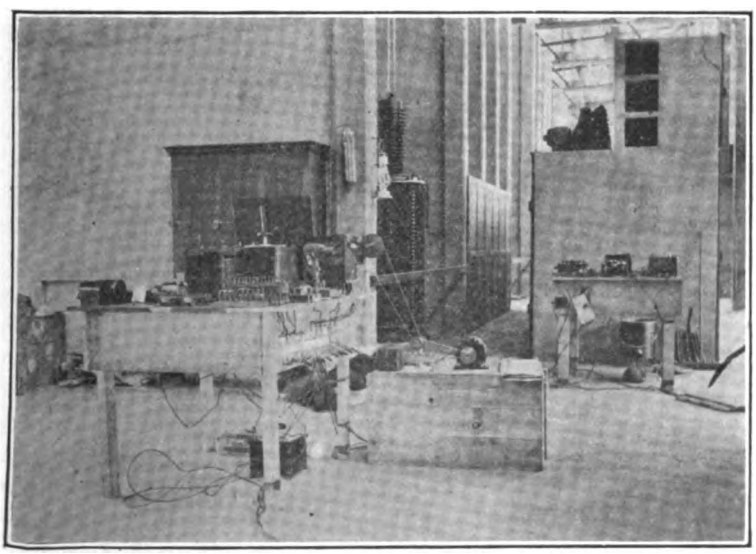


FIG. 18.—Oscillograph and testing equipment at Big Bend

When the switching took place at one station with the oscillograph located at another, a telephone and two or three additional men were needed in the signalling chain. As described in the paper, Records 18 and 20 were taken at Big Bend Power Plant, while the switching was done at Oakland, 154 miles distant (see map, Fig. 1). The oscillograph set-up and the station layouts necessitated a singaling chain consisting of five men; the oscillograph operator, an intermediary and a telephone attendant at Big Bend; a telephone attendant and a switchboard attendant at Oakland. In addition to allowing time for

Digitized by Google

the transmission of the signals, it was necessary to make an allowance for the lag in the switch mechanism, which was sometimes appreciable.

Several exposures were made in which a line was switched on and off the generating system and both operations recorded on the same film.

To assist in judging the proper time to be allowed for the transmission of the signals, etc., one trial switching operation was usually performed, the movement of the beam of light being noted on a ground glass inserted in place of the film.

None of the records given in the foregoing paper show more than 10 in. of the 48 in. of the film exposed, with the exception of Record 15, which shows 20 in.

In most of the exposures the zero line was not recorded, as it was not necessary and only complicated the records. To record the zero line the procedure with the short films is to make a second exposure with the vibrator switches open. With the long films a second exposure is not possible, but the zero line is recorded at the time of the original exposure by using the beam from the third or idle vibrator.

When two vibrators were in use it was found most satisfactory to cause their zero positions to coincide, in some cases reversing one of the waves, to better distinguish them when the two waves were nearly in phase. A few records were taken in which the zero positions of two waves were widely separated, thus separating the waves and preventing confusion. This, however, necessitated waves of small amplitude, and owing to the uncertainty as to the probable amplitude during an oscillation the method of using coinciding zeros in the center of the film was found most suitable.

The unloading is done in a dark room. To unload the standard film, the cover is removed, the drum taken out and the film unfastened—the reverse of the loading operation. With the long films it is only necessary to loosen the hooks and remove the wooden box. The film is then pulled out through the aperture in the holder. The cover and the driving pin need never be removed.

During all the switching operations one terminal of the vibrator was connected to one of the poles of the electromagnet between which it vibrated, in order to eliminate the effects due to electrostatic differences of potential, which were sometimes present.

Digitized by Google

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

THE USE OF POWER-LIMITING REACTANCES WITH LARGE TURBO-ALTERNATORS.

BY R. F. SCHUCHARDT AND E. O. SCHWEITZER

INTRODUCTION

In large electric power systems the maintenance of a very high degree of reliability, that is, continuity and uniformity of service, must be the constant aim and is one of the principal problems of the engineer. While the problems during the earlier years of central station work often appeared very difficult, the advent of the large capacity, high-speed turbo-generators coupled to systems containing hundreds of miles of transmission lines, made them much more complex and they took on a far more serious aspect.

The question most actively before some of the larger electric power companies at the present time is that of limiting the amount of energy which can flow into a fault. The solution in some instances of present turbo-generator installations will probably be the installation of current limiting reactances. It is the purpose of this paper to present some of the data obtained during a long series of unusual tests made during February, March and April of this year, on such reactances in conjunction with a large turbo-generator and to offer a few conclusions based on the results.

EVOLUTION OF ENGINEERING IN THE SYSTEM OF A LARGE CITY

In tracing the various steps in the evolution of the engineering with respect to provisions for safe-guarding the generating apparatus, the writers naturally cite the experience of the system with which they are most familiar, namely, that of the Commonwealth Edison Company and its predecessor companies. The

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

troubles of the stations of the early years are quite well known and in the light of present knowledge were comparatively simple. No time will be taken in this paper for their consideration. This applies to stations down to and including the time of slow-speed alternators direct coupled to reciprocating engines and feeding a transmission system of some considerable size. It was not until the introduction of the high-speed turbo-alternators that serious troubles were experienced which indicated that these later units had characteristics quite different from those of their engine-driven predecessors.

The experience in Chicago during the past eight years, that is, since the operation of the Fisk Street Station with its pioneer 5000-kw. turbo-generators was begun, showed an increasing severity in the disturbances (due to apparatus and cable breakdowns) with the growth of the stations and, therefore, apparently due to the increase in generator capacity. This can perhaps be better appreciated when we remember that previous to October, 1903, the total capacity in high voltage alternators on the system of the then Chicago Edison Company amounted to 9800 kw., while in October, 1911, the total capacity of the three large stations will aggregate about 250,000 kw.

The original 5000-kw. generators at Fisk Street, of which there were four, had their neutrals grounded solidly. These were all 9000-volt six-pole machines operating at 500 rev. per min. The fifth unit to be installed was of larger capacity and, having four poles, operating at a speed of 750 rev. per min. It was found that with the neutral of this fifth unit closed to ground a comparatively heavy cross current flowed between it and the other units, and a neutral resistance of approximately $2\frac{1}{2}$ ohms was installed on the new unit. This resistance incidentally served to limit the current which would flow into grounded apparatus or cable ("Y" pressure of the generators is 5200 volts). All additional units were, therefore, provided with neutral resistances and later the solid connections to ground of the four original units were removed. To further limit the current flowing into a single-phase fault, the neutral was closed on only one of the units operating on the system. With the continually increasing capacity the exact effect of these various changes could, of course, not be determined, as breakdowns in apparatus or in cable do not occur with great frequency and in most cases the conditions are so involved that the effects cannot be accurately analyzed. It is easily seen, though, that

Digitized by Google

these various steps must have served to reduce the energy flowing into a single phase fault.

Disturbances were, however, still of sufficient severity occasionally to have a widespread effect and the system was, therefore, divided into sections so that a fault was reduced in severity and limited to one section, leaving the remainder of the system undisturbed. This was going back in part to the original method of operating this station, each unit initially having fed only its own lines independent of the other units. The maximum capacity now permitted on each section was set at 50,000 kw. Even with these precautions, however, severe disturbances occurred and especially at times when the generator armatures themselves developed faults. In the four years from 1906 to 1909 inclusive, there were seven generator burn-outs, all of which caused a temporary shut-down of part or all of the substation apparatus on the section to which the particular generator was connected. The storage batteries, of course, meanwhile maintained the service in the direct-current districts. In practically all of these cases the armature end turns were torn loose and the windings were pretty well wrecked. It was then appreciated more strongly than ever before that a more rigid construction of the generator was necessary and the armatures were rewound with a new form of coil with a very much improved arrangement of end turns; also, one coil was laid in a slot instead of two, as in the former winding. The experience thus far apparently indicates that this improvement is satisfactory. With severe short circuits the switches continued occasionally to give considerable trouble and in one or two instances actually failed.

On the 20,000 volt system fed normally through two 5000-kw. transformers from the 9000-volt system which transformers originally had a reactance of approximately $2\frac{1}{2}$ per cent, cable breakdowns in four instances caused disastrous results within the transformer, completely wrecking part of the winding.

Need for Increased Reactance

The absolute necessity for reducing the current which can flow into a fault was now very clear. As this current is a function of the reactance of the circuit it was apparent that the reactance must be increased. The transformers were rewound in a manner to give an internal reactance of approximately $4\frac{1}{2}$ per cent. An additional amount could be added externally. In the case of

Digitized by Google

the generators the higher value of reactance could, of course, be taken care of in new designs. In new units of very large capacity it was thought best to divide the desired total reactance between the generator itself, winding it for comparatively low voltage, and an auto-transformer which would serve to step up the voltage to the required value. The major duty of withstanding the shocks caused by system disturbances, was thus placed on a device external to the generator. In the case of existing units the additional reactance could best be supplied by the use of external coils which would serve also as a buffer against potential risk and relieve the generator of excessive short circuit strains. The installation of an induction generator would have introduced numerous complications and was, therefore, not considered.

Reactances for Transformers

For the transformers above mentioned, further additional reactance was provided in the form of external coils of approximately 4 per cent reactance (that is, designed to absorb 4 per cent of the "Y" voltage at full load current). These were connected in series on the primary or 9000 volt leads. They have now been in service nearly two years and during that time the transformers have successfully withstood a number of short circuits of a kind which previously had caused them to be wrecked.

Reactances for Generators

In the case of the generators the installation of reactances presented a far more serious problem. There was a natural hesitancy at the beginning in installing apparatus on which so little definite knowledge was available and which required a considerable outlay of money for its installation. In order to house the coils at Fisk Street, for instance, an addition was required along the entire length of the switch house, while at Quarry Street where there are four 25-cycle units of 14,000-kw. capacity each, part of an excitation storage battery had to be moved and material structural changes made to provide the necessary room.

Purpose of and Preparation for Tests

In view of the large investment required and the possible hazards that might result, it was deemed desirable to learn more about the actual behavior of the proposed coils and their effectiveness toward the desired results before proceeding with their

Digitized by Google

installation and for this purpose an elaborate and very complete series of tests was conducted, using one of the 12,000-kw., 9000-volt, 25-cycle turbo-generators at the Fisk Street Station.

All conductors of this unit, that is, armature and field leads and all meter and control wires, were disconnected from their regular service and connected temporarily to points outside of the station. A section of the basement at the end of the building was partitioned off and the reactances were installed therein. A temporary structure was erected in the yard outside of the station building and in this were placed two oil switches, one for making the short circuit on the 12,000-kw. unit and the other for opening this short circuit. The very unusual opportunity offered for studying the action of oil switches was taken advantage of and a number of tests were made on such switches, the results of which are presented at this Convention in a paper by Mr. E. B. Merriam.

One end of a construction shop located in the yard about 50 ft. from the oil switch structure and from which a full view of the switches was had, was temporarily converted into a control center and in this were placed two oscillographs, terminal boards for the control and meter wiring, and suitable panels carrying the switches and meters. A telephone system was installed between this temporary control center and a convenient point in the turbine room and all the work to be done by the large number of attendants and observers was thoroughly organized so the tests could be made safely and expeditiously.

The points to be determined by the tests were the following:

1. The instantaneous short circuit current of turbo-generator without external reactance.
2. The instantaneous short circuit current of turbo-generator with an external reactance of 4 per cent.
3. The instantaneous short circuit current of turbo-generator with an external reactance of 6 per cent.
4. Duration of the transient phenomena incident to the short circuits under conditions 1, 2 and 3.
5. The effect on the generator of these short circuit currents.
6. The behavior of the reactance coils.
7. The effect of the installation of reactance coils on the stability of the system.

Description of Apparatus Tested

The unit selected is turbo-generator No. 10 and is shown in Fig. 1. The generator has a " barrel coil " winding made up of 36 coils, four turns per coil, laid in 72 slots. The resistance of the

Digitized by Google

armature per phase of the "Y" winding is 0.0244 ohms at 25 deg. cent. From calculations made to determine the armature impedance, it was found that this is approximately 2 per cent. This value, however, does not include consideration of transient constants and the effective reactance at time of short circuit is in excess of this value due to several causes chief of which is the rapid dying down of the field, as is clearly brought out in the data presented. The full load current is 770 amperes. Fig. 2 shows a view of the armature winding, the field being removed, and incidentally illustrates the new form of end turn construction.

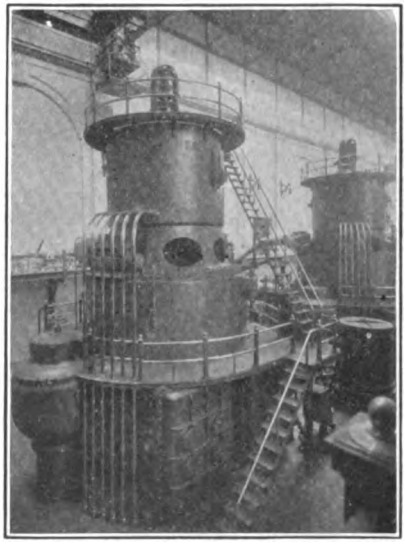


FIG. 1

The field is of the indefinite pole, laminated core type. Its resistance is 0.238 ohms at 25 deg. cent. measured from the terminals at the collector rings. The full load excitation with unity power factor is approximately 400 amperes. Fig. 3 shows the field. The ends are shown covered with boiler plate. The winding can, therefore, not be seen except where it passes the air ducts.

A set of three reactance coils, one for each phase, was used. This is shown in Fig. 4 and was designed for a reactance voltage at 25 cycles of 312 per coil (6 per cent of the Y voltage) with a

Digitized by Google

current of 770 amperes. Each coil has 76 turns of 1,000,000-cir. mil cable wound on a hollow concrete core having no iron in any part. The inner diameter of the turns is approximately 2 ft., 10 in., and the outer diameter about 4 ft. 3 in. The inner layer has 26 turns, the middle has 24, and the outer layer 26 turns. The vertical distance between turns is three in. and the horizontal distance between layers is $2\frac{1}{4}$ in. The diameter of the copper is approximately $1\frac{3}{16}$ in. The coils used in the tests have an outer layer of $\frac{1}{2}$-in. cord, as shown in the figure. This is for the purpose of preventing persons or materials coming in contact with the bare conductors. The total height of the coil structure is approximately eight ft., and the copper turns extend

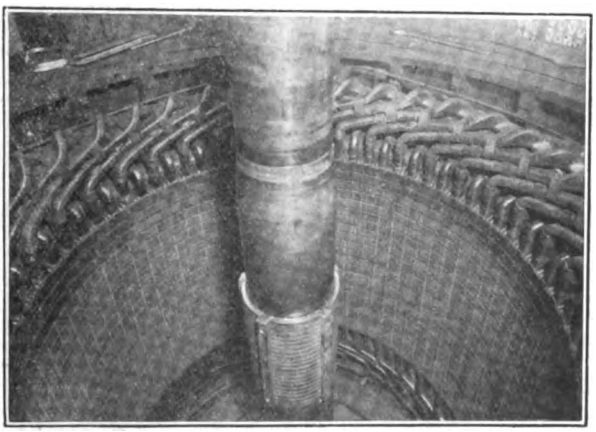


FIG. 2

over about three-fourths of this height. By measurement the impedance of each coil at 25 cycles is 0.425 and the resistance 0.0075 ohms. The coils were installed six ft. between centers and anchored into the concrete floor and braced at the top by 6-in. by 6-in. oak beams, 14 ft. long. The clearance between copper of adjacent coils was 27 in.

The connections were made as shown in Fig. 5.

DESCRIPTION OF TESTS

The short-circuiting switch was closed in all cases with the generator at full speed. A total of 167 short-circuit tests were thus made of which 88 were at full voltage, 38 at one-half to

Digitized by Google

full voltage, and 41 at less than one-half voltage. With the exception of a few tests as noted in Table V and VI the neutral connection of the generator was solidly grounded throughout the series. In the case of the exceptions a $2\frac{1}{2}$ ohm resistance (one of the regular neutral rheostats used at the station) was inserted in this neutral connection. Two oscillographs were used, as shown in Fig. 5, and records were obtained of various currents and pressures, as indicated below.

The initial tests were, for safety, made at low voltage and these

FIG. 3

were followed by a large number of tests under various conditions, the majority, as already stated, being at normal voltage. The principal data obtained are given below. The pressure traces of the oscillograms were obtained from the secondary of 200 watt potential transformers, ratios 100 to 1 and 120 to 1, (see Fig. 5), and the current traces from the secondaries of type S current transformers, the ratio being selected with reference to the probable primary current. To test the effect of stray field from the reactance coils upon the 120 to 1 current transformers used to get oscillograms of generator currents and

Digitized by Google

which were placed about six feet from the reactances, a 400 to 1 current transformer was installed on the *A* phase of the armature leads on the turbine room floor at least 30 ft. from the reactances. Comparative oscillogram curves are shown taken from this transformer and the regular transformer. The first rush of current as shown by the two transformers checks closely, but considerable discrepancies exist in the current values during the later cycles. In all oscillograms except those shown in Figs. 6, 24 and 26, 400 to 1 current transformers were used instead of 120 to 1 current transformers for the traces of generator currents.

Unfortunately in mounting the oscillograms, special attention was not paid to arranging the two prints, where two oscillograms

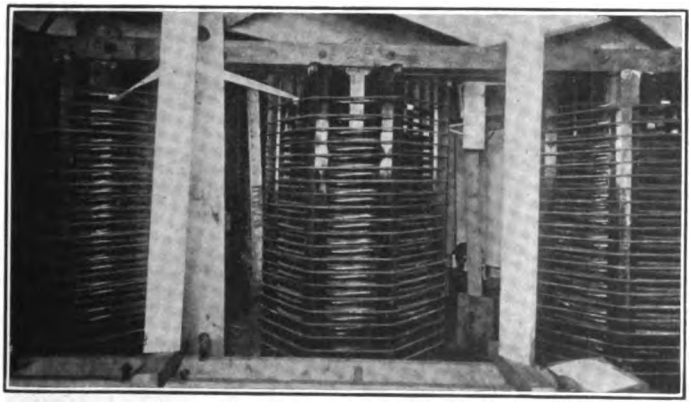


FIG. 4

were taken at one time, so that simultaneous occurrences would appear in line. Because of the time limitation it was impossible to correct this before the illustrations had to be sent in for reproduction. However, the simultaneous sequence of events is so clearly shown that the occurrences can readily be studied with relation to each other. In all cases the sequence of events illustrated on oscillograms is from left to right and in the identification marked below the curves, the traces are read from top to bottom. In connection with the study of the various waves it should be stated that the absolute phase rotation of the system is in the direction C. B. A.

Considerable data can be obtained from these oscillograms which is of great value and interest in the study of the charac-

Digitized by Google

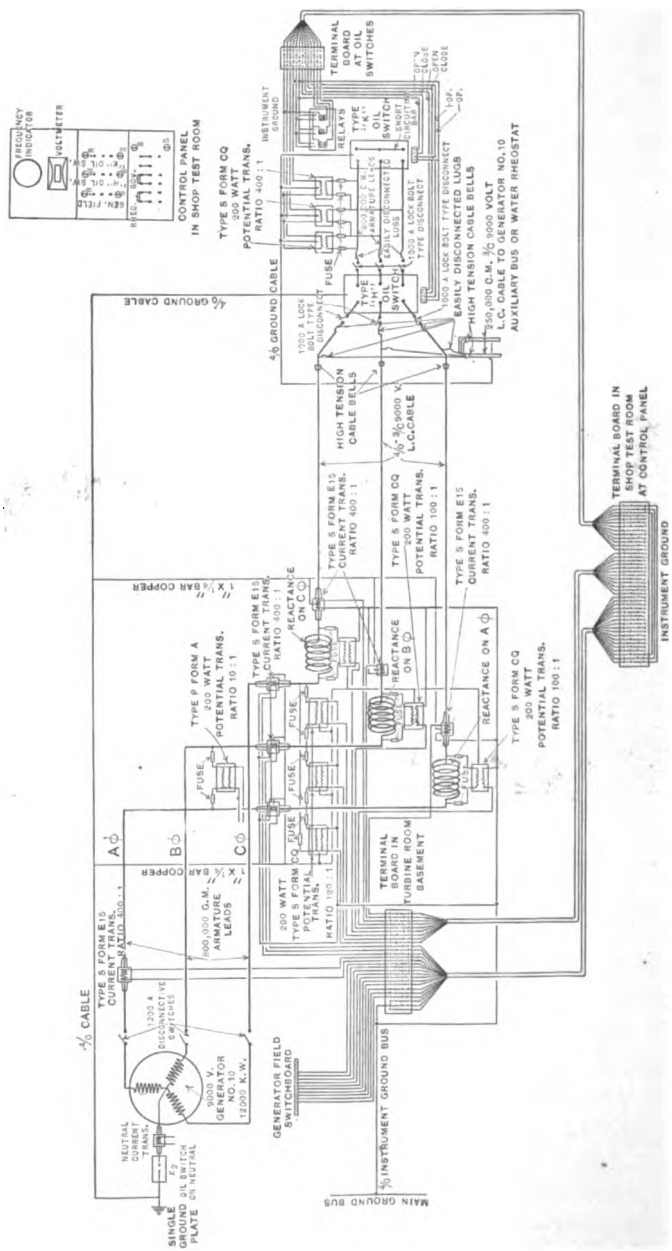
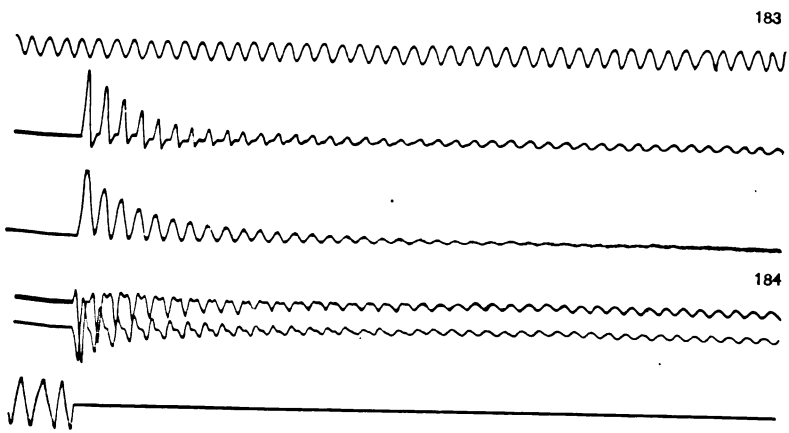

FREQUENCY INDICATOR
VOLTMETER
CONTROL PANEL IN SHOP TEST ROOM
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 400 : 1
INSTRUMENT GROUND
TERMINAL BOARD AT OIL SWITCHES
RELAYS
TYPE K OIL SWITCH
SHORT CIRCUITING LUGS
1200 A LOCK BOLT TYPE DISCONNECT
FUSE
TYPE K OIL SWITCH
1200 A LOCK BOLT TYPE DISCONNECT
EARTH DISCONNECTING LUGS
HIGH TENSION CABLE BELLS
200,000 C.M. 9000 VOLT L.C. CABLE TO GENERATOR NO. 10 AUXILIARY BUS OR WATER RHEOSTAT
TERMINAL BOARD IN SHOP TEST ROOM AT CONTROL PANEL
INSTRUMENT GROUND
⅛ GROUND CABLE
⅛ BAR COPPER
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 400 : 1
TYPE S FORM E15 CURRENT TRANS. RATIO 100 : 1
REACTANCE ON C Φ
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 100 : 1
⅛-9000 V. L.C. CABLE
REACTANCE ON B Φ
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
REACTANCE ON A Φ
TYPE S FORM CQ 200 WATT POTENTIAL TRANS. RATIO 100 : 1
TYPE P FORM A 200 WATT POTENTIAL TRANS. RATIO 10 : 1
FUSE
TERMINAL BOARD IN TURBINE ROOM BASEMENT
TYPE S FORM E15 CURRENT TRANS. RATIO 400 : 1
1200 A DISCONNECTING SWITCHES
200,000 C.M. ARMATURE LEADS
9000 V. GENERATOR NO. 10 12000 K.W.
NEUTRAL CURRENT TRANS.
SINGLE GROUND PLATE
OIL SWITCH ON NEUTRAL
GENERATOR FIELD SWITCHBOARD
⅛ INSTRUMENT GROUND BUS
MAIN GROUND BUS
⅛ CABLE

FIG. 5

Digitized by Google

teristics of turbo-generators of the type under test but the practical bearing of some of this data is somewhat remote and because of the extreme length to which this paper would otherwise have to be carried, considerable of it is omitted. Thus for instance, the value and characteristic of the field current under the various conditions comes in this class. This and other of the data open up a vast field for study and many of the questions in connection with them would of themselves and with the test data furnish sufficient material for a long paper. Many of the



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 6,700 amperes per in.
3—Generator field current; scale 1,100 amperes per in.
4—*A* phase generator current; scale 7,900 amperes per in.
5—*B* phase generator current; scale 9,400 amperes per in.
6—*A B* generator delta pressure; scale 11,000 volts per in.

FIG. 6.—Oscillograms of a three-phase short circuit with no external reactance at 3,000 volts generator delta pressure with steam on turbines

oscillograms contain a trace obtained from the field current and these traces show in a general way the action of the field.

THE TESTS

1. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITHOUT EXTERNAL REACTANCE

In order to determine as nearly as possible the exact effect of the reactances in limiting the energy flowing into a fault it was necessary to obtain data of turbo-generator characteristics without external coils. It was obviously unsafe to carry this to the limit of normal voltage but tests were made at voltages from

NOTE:—The scale values given for these oscillograms refer to the original curves. All of the reproductions of oscillograms in this paper are one-third of the original size.

Digitized by Google

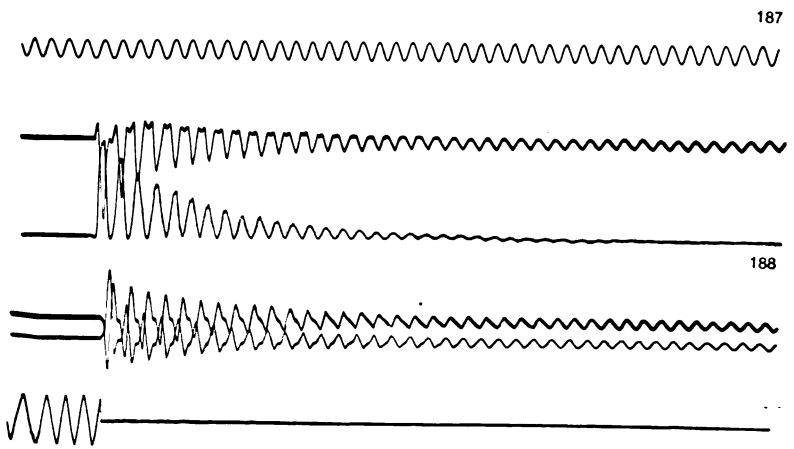
TABLE I.

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
54	137	0	H-3	3 φ	1000						1800	
55	139	0	"	"	1000						4550	
56	141, 142, 143	0	"	"	2000	+ 58%	— 41%	— 99%		5200	3100	
57	144	0	"	"	3000	+ 80%	— 11%	— 92%		9400	6100	
58	147, 148	0	"	"	3000	— 99%	+ 57%	— 43%		7800	7800	
78	179, 180, 181	0	"	"	3000	+ 50%	— 50%	100%	7260	9400	6000	
79	182, 183	0	"	"	3000	— 7%	— 89%	+ 82%	7100	7500	4000	
80	184	0	"	"	3000	— 48%	100%	+ 52%	6900	4700	6700	See Fig. 6.
81	185, 186, 187	0	"	"	3000	+ 74%	— 22%	— 95%	6700	9400	6400	Steam shut off just before short circuit.
82	188, 189	0	"	"	3000	+ 94%	+ 18%	— 76%	6000	8200	8240	See Fig. 7
83	190, 191	0	"	"	3000	— 98%	+ 66%	— 32%	5760	8940	8700	
84	192, 193	0	"	"	4000	— 87%	+ 87%	0%	9230	8800	7600	
85	194, 195	0	"	"	4000	— 33%	— 98%	+ 65%	9720	7700	7360	See Fig. 8
86	196, 197	0	"	"	4000	— 39%	— 99%	+ 66%	9920	6800	8500	Steam shut off just before short circuit.
87	198, 199	0	"	"	4000	+ 87%	— 87%	0%	9520	7460	9900	See Fig. 9
88	200, 201	0	"	"	4000	— 35%	— 98%	+ 63%	9720	12200	8200	
89	202	0	"	"	4000	100%	+ 57%	— 43%	7200	11850	11300	See Fig. 10

+ Represents increasing wave. — Represents decreasing wave.

Digitized by Google

1000 to 4000. Data of seventeen of these tests are given in Table I and the principal characteristics are illustrated in Figs. 6 to 10 inclusive. A time reference wave taken from the 25-cycle system was used to determine the retardation of the turbine but these traces show no appreciable retardation within the time covered by the film. In later tests with a slower speed of film revolution a retardation of $\frac{1}{4}$ cycle in five seconds was found. The values of current and pressure of these oscillograms are given in the table. The maximum field current shown in Fig. 6 had a value of approximately 1200 amperes; in Fig. 7, 1740



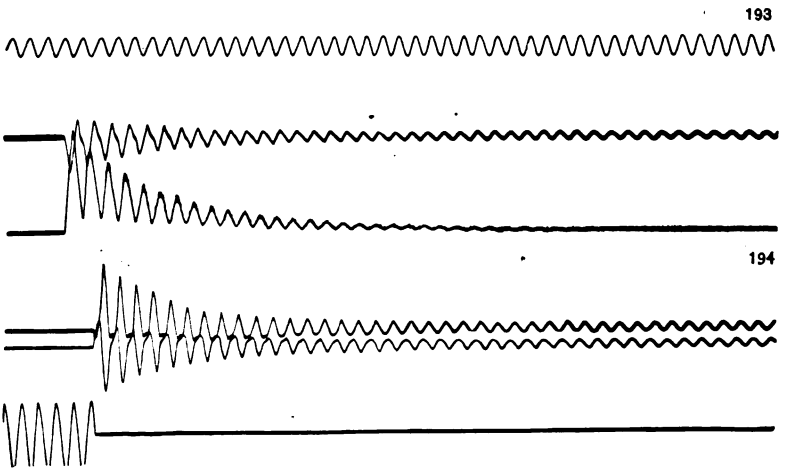
Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 6,700 amperes per in.
3—Generator field current; scale 1,100 amperes per in.
4—*A* phase generator current; scale 7,900 amperes per in.
5—*B* phase generator current; scale 9,400 amperes per in.
6—*A B* generator delta pressure; scale 11,000 volts per in.

FIG. 7.—Oscillograms of a three-phase short circuit with no external reactance at 3,000 volts generator delta pressure without steam on turbine

amperes; in Fig. 8, 1850 amperes, in Fig. 9, 2000 amperes and in Fig. 10, 2400 amperes. The various data regarding the condition of the field circuit are omitted for reasons given in preceding paragraph.

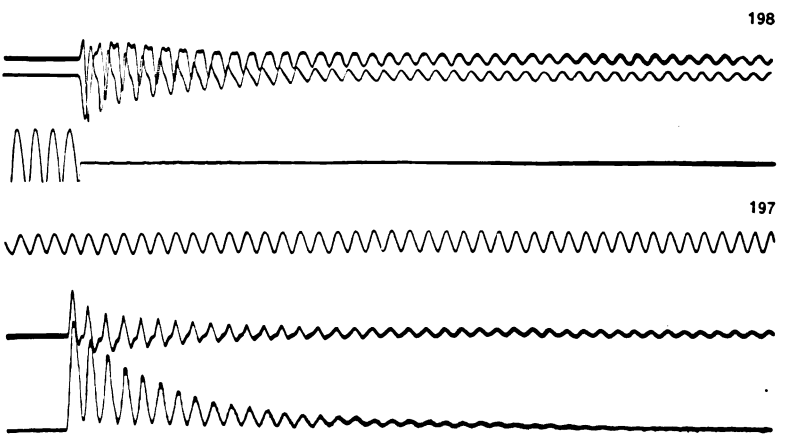
In the tests illustrated by Figs. 7 and 9 the unit was first brought above synchronous speed. Steam was then shut off when the speed had dropped to exactly 25 cycles the short-circuiting switch was closed. The oscillograms show that the retardation of the turbine (at the pressures tested) is not affected by the presence or absence of the steam. In other words, it is

Digitized by Google



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 14,100 amperes per in.
3—Generator field current; scale 1,100 amperes per in.
4—*A* phase generator current; scale 9,720 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; 11,000 volts per in.

FIG. 8.—Oscillograms of a three phase short circuit with no external reactance at 4,000 volts generator delta pressure with steam on turbine



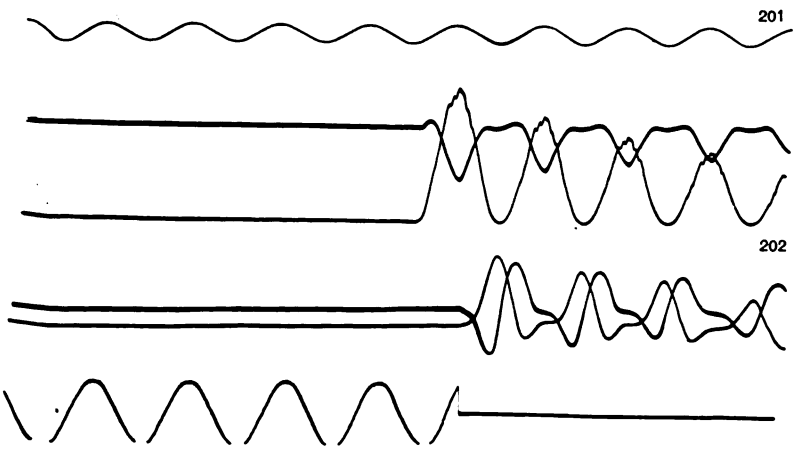
Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 14,100 amperes per in.
3—Generator field current; scale 1,100 amperes per in.
4—*A* phase generator current; scale 9,720 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; 11,000 volts per in.

FIG. 9.—Oscillograms of a three-phase short circuit with no external reactance at 4,000 volts generator delta pressure taken without steam on turbine

Digitized by Google

entirely a matter of stored energy in the moving mass. In Fig. 8 an interesting trace of field current is shown. The first rush is apparently composed of an alternating current superimposed on the direct current and both were added to the normal excitation current. Both the direct current and alternating current components disappeared simultaneously and at the end of approximately one second the normal value of excitation current was restored. The oscillograms of Fig. 10 were taken to show the wave forms of the generators and the field currents.

From the data obtained from these traces the maximum cur-



Trace No. 1—Time reference wave from 25-cycle system.
2—*C* phase generator current; scale 14,100 amperes per in.
3—Generator field current; scale 1,100 amperes per in.
4—*A* phase generator current; scale 9,720 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; scale 11,000 volts per in.

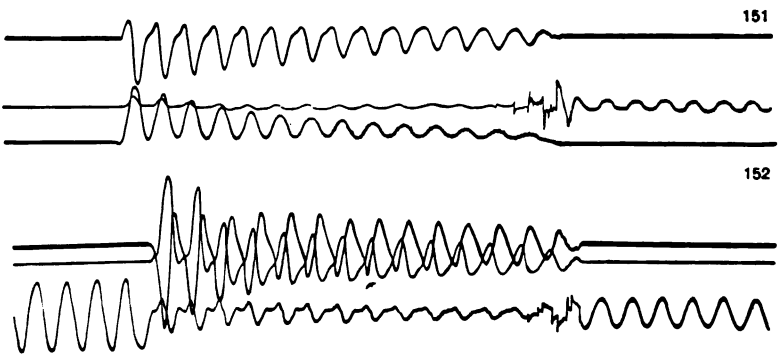
FIG. 10.—Oscillograms of a three-phase short circuit with no external reactance at 4,000 volts generator delta pressure with steam

rent at 3000 volts was shown to be 9800 amperes and at 4000 volts 13,000 amperes. Assuming that this proportionality to voltage holds up to normal pressure then the maximum current at normal voltage will be approximately 29,000 amperes or 27 times full load current.

2. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITH AN EXTERNAL REACTANCE OF 4 PER CENT

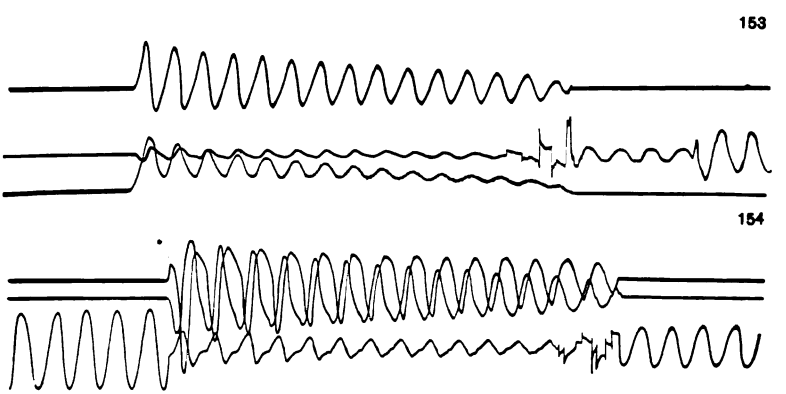
It was suggested that perhaps 6 per cent is too high a value for the external reactances and for the purpose of determining the

Digitized by Google



Trace No. 1—*C* phase generator current; scale 14,100 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 5,500 volts per in
3—Generator field current; scale 2,800 amperes per in.
4—*A* phase generator current; scale 9,560 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 11.—Oscillograms of a three-phase short circuit with an external reactance of 4 per cent at 7,000 volts generator delta pressure

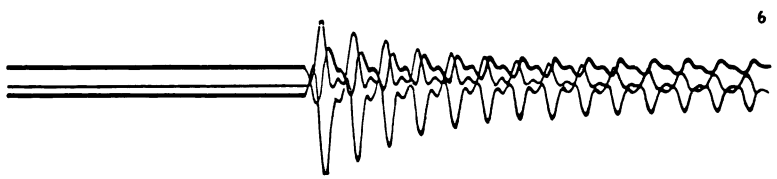


Trace No. 1—*C* phase generator current; scale 14,100 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 5,500 volts per in.
3—Generator field current; scale 2,800 amperes per in.
4—*A* phase generator current; scale 9,560 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 12.—Oscillograms of a three-phase short circuit with an external reactance of 4 per cent at 8,000 volts generator delta pressure

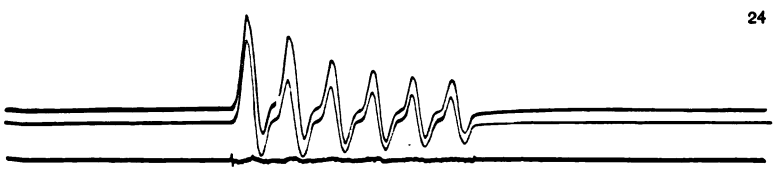
Digitized by Google

effect of the lesser amount a series of tests was made with an external reactance of 4 per cent, using for this purpose part of the turns of the 6 per cent coils. By measurement the section used had a reactance of 0.27 ohms at 25 cycles, thus absorbing 208 volts with a flow of full load current. The data of four of these tests are given in Table II and in the curves of Figs. 11 and 12. Aside from some peculiar pressure conditions at the oil switch no points of particular importance are brought out by the oscillograms. Tests were not made at a pressure higher than 8000 volts



Trace No. 1—*A* phase generator current; 1,560 amperes per in.
2—*B* phase generator current; 1,200 amperes per in.
3—*C* phase generator current; scale 770 amperes per in.

FIG. 13.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 1,060 volts generator delta pressure



Trace No. 1—*A* phase generator current from special current transformer; scale 2,640 amperes per in.
2—*A* phase generator current from regular current transformer; scale 2,880 amperes per in.
3—Defective potential transformer fuse.

FIG. 14.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 3,000 volts generator delta pressure

with this reactance as the current rushes at that pressure were so high that it was thought inadvisable to subject to the generator or the switches to a greater strain. The current values obtained indicate that at 9000 volts the maximum current would be approximately 18,000 amperes, or $16\frac{1}{2}$ times full load current.

3. THE INSTANTANEOUS SHORT CIRCUIT CURRENT WITH AN EXTERNAL REACTANCE OF 6 PER CENT

There were 146 short circuits made through the 6 per cent reactances. A number of these tests, in addition to determining

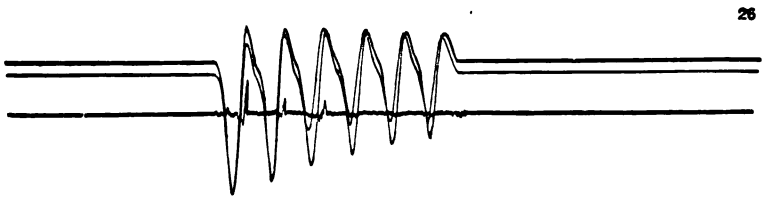
Digitized by Google

TABLE II

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
59	149, 150, 151	4	H-3	3 ϕ	5000	+ 83%	— 6%	— 89%	7200	10200	7800	
60	152, 153	4	"	"	7000	+ 58%	— 41%	— 99%	12000	14700	9900	See Fig. 11
61	154, 155	4	"	"	8000	— 39%	— 99%	+ 60%	13400	10400	9900	See Fig. 12
62	156	4	"	"	8000	+ 97%	+ 28%	— 69%	10500	14100	14850	

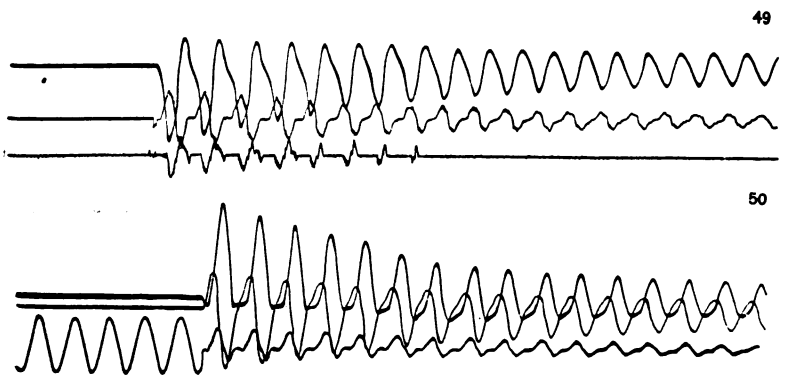
Digitized by Google

the characteristics and behavior of the reactances, were made for the purpose of experimentation on the oil switches and a few on potential transformer fuses. From the oscillograms obtained, the characteristics of the reactances were studied. In Table III are given the data of twenty-one of these tests and the principal



Trace No. 1—*A* phase generator current from special current transformer; scale 2,640 amperes per in.
2—*A* phase generator current from regular current transformer; scale 2,880 amperes per in.
3—Defective potential transformer fuse.

FIG. 15.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 4,000 volts generator delta pressure



Trace No. 1—*C* phase generator current; scale 5,700 amperes per in.
2—*A* phase reactance coil drop; scale 6,230 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 5,200 amperes per in.
5—*B* phase generator current; 6,300 amperes per in.
6—*A B* generator delta pressure; 18,100 volts per in.

FIG. 16.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 5,500 volts generator delta pressure

characteristics are illustrated in Fig. 13 to 20 inclusive. A very interesting fact is brought out in these oscillograms. The maximum pressure across the reactance coils is shown to occur in the latter half of the first cycle, indicating that the rate of change of the current is greater in the latter part of the first cycle than in the initial rush. Figs. 13 to 18 inclusive were

Digitized by Google

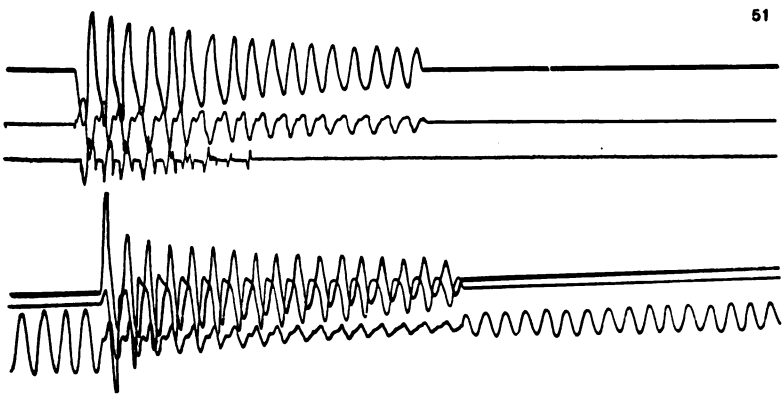
TABLE III

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
1	6	6	H-6	3 φ	1050				860	1250	960	See Fig. 13
2	7	6	"	"	1080				1200	1100	770	
3	8	6	"	"	1470				1000	1300	1150	
4	9	6	"	"	1780				1750	1700	2350	
7	21	6	"	"	2000				1450	Regular		
8	23	6	"	"	2500				3550	Regular		
9	24	6	"	"	3000				3600	Regular		See Fig. 14
11	26	6	"	"	4000				5300	Regular		See Fig. 15
14	45 46	6	"	"	4500	+ 99%	— 56%	+ 43%	5700	4400	6560	
15	48	6	"	"	5000	+ 50%	— 50%	100%	6800	6800		
16	49 50 51	6	"	"	5500	— 26%	— 97%	+ 72%	7650	5900	6600	See Fig. 16
17	52 53	6	"	"	6000	+ 50%	— 50%	100%	8300	8800	5100	See Fig. 17
18	54 55	6	"	"	6500	— 12%	— 92%	+ 80%	9100	7560	7400	
19	56 57	6	"	"	7000	+ 89%	+ 7%	— 83%	8200	11300	9700	
20	58 59	6	"	"	7500	+ 55%	— 45%	— 99%	12400	12200		
21	60 61	6	"	"	8000	— 99%	+ 53%	— 47%	7850	13400	14200	See Fig. 18
22	62 107	6	"	"	8500	+ 99%	+ 42%	— 57%	8500	14700	13500	
41	108 117	6	H-3	3 phase grounded *B* phase	6000	+ 2%	+ 2%	— 86%	7200	9800	8900	
45	118 119	6	"	to ground *B* phase	9000	+ 47%	— 52%	+100%		15800		See Fig. 19
46	120 121	6	"	to ground *B* phase	9000	— 63%	+ 98%	+ 35%		8800		
47	122	6	"	to ground	9000	— 52%	+100%	+ 48%		9300		See Fig. 20

Digitized by Google

obtained with three phase short circuits while Figs. 19 and 20 show single-phase short circuits to ground. These latter show the double-frequency field current due to single-phase short circuits and also the pressure rise on the opposite phases. The maximum value of the current obtained during the short circuits with the 6 per cent reactance and at 9000 volts was 15,800 amperes, which is 14½ times full load current.

The wave forms of the current through the reactances as well as the voltage across them were also determined, the circuit for this purpose being closed through the short circuiting bar and the field excitation being adjusted for the full load current of



Trace No. 1—*C* phase generator current; scale 5,700 amperes per in.
2—*A* phase reactance coil drop; scale 6,230 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 5,200 amperes per in.
5—*B* phase generator current; 6,300 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

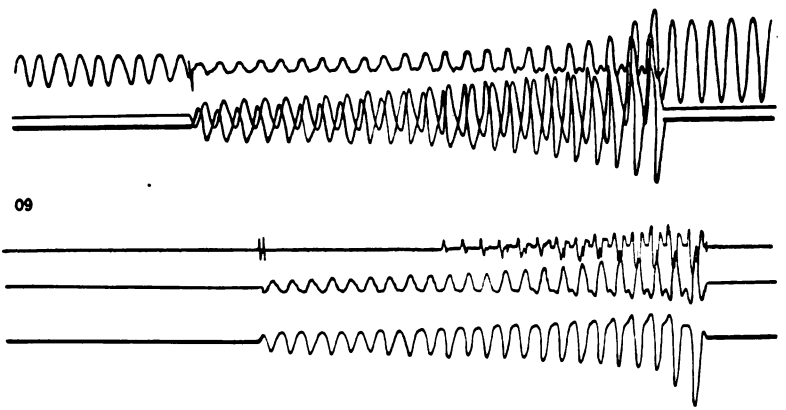
FIG. 17.—Oscillograms of a three-phase short with an external reactance of 6 per cent at 6,000 volts generator delta pressure

the turbo-generator. The traces obtained under these conditions are shown in Fig. 21. The measured voltage across each coil with this full load current is 328 volts, or a drop of 6.3 per cent.

In order to determine whether the amount of steam entering the turbine at the time of a short circuit had any effect on the results, these tests were further extended by including a series in which a load was placed on the turbo-generator and while carrying the same the short circuit was applied. Apparently the results of short circuiting a generator with load are no different from those in which the turbo-generator has no load.

Digitized by Google

Considerable discussion has been heard in regard to the probable rises in voltage due to non-simultaneous opening of the three phases of the oil switch. In eighteen of the tests made with 6 per cent reactance coils, such non-simultaneous opening is clearly indicated. The voltage rises at the switch are shown in Table III*b*, while Figs. 22 to 27, inclusive, show some of the characteristics under these conditions. Figs. 24 and 25 indicate that some of the contacts of the switch had become badly pitted which was, of course, to be expected after the very severe and continued service during the short circuits. A maximum



Trace No. 1—*B* phase generator current; scale 13,500 amperes per in.
2—*A* phase reactance coil drop; scale 8,700 volts per in.
3—Defective potential transformer fuse.
4—*A* phase generator current; scale 7,840 amperes per in.
5—*B* phase generator current; scale 9,040 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 18.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 8,000 volts generator delta pressure

voltage rise of over 200 per cent at some of the switch breaks is indicated in the oscillograms.

Single Phase Short Circuits with 6 per cent Reactance. The maximum current on a single phase to ground short circuit was 15,800 amperes, on a short circuit between two phases 12,900 amperes, and on the single phase to ground short circuit with neutral rheostat of 2.5 ohms, 2,580 amperes. Most of the single phase short circuits were made with the generator carrying substation load and pressures were taken across the load bus. Table VI shows the pressure rise on the generator and load bus. It shows that the maximum pressure rise without neutral rheo-

Digitized by Google

TABLE IIIB

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit: A ph. to ±	B ph. to ±	C ph. to ±	Maximum currents: A ph.	B ph.	C ph.	Pressures at oil switch: Closing switch: A ph. to ±	B ph. to ±	C ph. to ±	Opening switch: A ph. to ±	B ph. to ±	C ph. to ±	Remarks
159	269, 270, 271	6	K-12	3 φ	5000	—98%	+66%	—32%	9400		9350	7700	7200	None	6600	8800	7600	C phase to sw. closed ½ cy before B phase closed.
160	272	6	"	"	7000	+93%	+12%	—80%	8930		11050	12600	9600	None	5000	9600	None above normal	ditto.
163	275, 276	6	"	"	8000	+22%	—73%	+95%	13600		9020	None	9600	None	7700	9600	11200	B phase of sw. closed 10% later than C phase. See Fig. 22.
164	277, 278	6	"	"	8000	—32%	—98%	+63%	12200		9360	4400	11200		?	9600	None above normal	C phase of sw. closed before B phase and A phase.
165	285, 286	6	"	"	8000	—95%	+67%	—32%	8460		12400	10500	None	None	17000	12000	?	B phase of sw closed about 10% after C phase
42	109, 110, 111	6	H-3	"	8000	—98%	+65%	—33%	10200	11900	11000	None			2700	gen.	side	A phase of sw. closed 10% before C phase current.
43	112, 113	6	"	"	9000	+89%	+ 6%	—83%	10200	15800	12500	None			2700	gen.	side	ditto. See Fig. 23.
44	114	6	"	"	9000	—35%	—98%	+62%	12400	9000	7100	None			2200	gen.	side	ditto
166	279	6	K-12	"	9000						14950		12800	None		20800	17700	ditto
167	281, 282	6	"	"	9000	+81%	—11%	—92%	10340		12750	Over 22000	12800	None	13200	21100	16800	ditto. See Fig. 24.
168	283, 284	6	"	"	9000	—86%	+86%	0	7800		11900	Over 22000	12000	None	7100	14400	?	ditto. See Fig. 25.
170	287, 288	6	"	"	9000	—98%	+67%	—32%	11270		12750	Over 19000	12300	None	None	15200	None above normal	B phase of sw. closed ½ cy. after C phase and A phase.
171	289, 290	6	"	"	9000	+40%	—58%	+99%	16170		15300	17600	12800	None	8300	12000	"	B phase of switch closed 1 cy. after C phase. See Fig. 26.
172	291, 292, 293	6	H-3	"	9000	—60%	—99%	+39%	12880		14800							
173	294	6	"	"	9000	+70%	—27%	—97%	12220		10540							
202	337, 338	6	K-12-S	"	9000	100%	+50%	—50%	7700, 7950		12900		None	None		10400	None above normal	C phase of sw. closed 10% early. See Fig. 27.
203	339, 340, 341	6	"	"	9000	+95%	+23%	—72%	9400, 9900, 13450		11700		None	None		15200	16800	ditto
204	342	6	"	"	9000	—70%	+97%	+27%	13400		15800		None	None		None above normal	11200	ditto

Digitized by Google

TABLE IIIA

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
24	69 70	6	H-6	3 φ with load	9000	— 15%	— 93%	+ 78%	14100	12200	10800	Water rheostat load of 2000 kw.
26	71 72	6	"	"	9000	— 82%	+ 92%	+ 9%	12000	9300	14600	Water rheostat load of 6000 kw.
27	73 74	6	"	"	9000	— 72	+ 96%	+ 24%	9400	9700	14200	ditto 7440 kw.
28	75 76	6	"	"	9000	— 63%	+ 98%	+ 36%	11500	8000	12800	ditto 7880 kw.
29	77 78	6	"	"	9000	— 93%	+ 76%	— 18%	10000	12000	14200	ditto 7880 kw.

TABLE IV

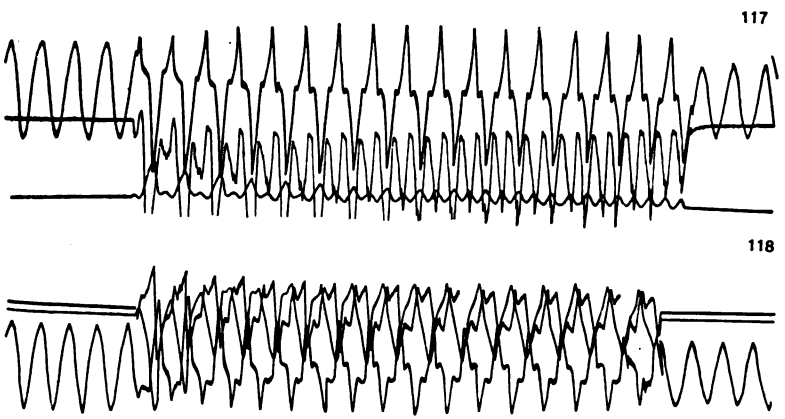
Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	B ph. to ±	C ph. to ±	A ph.	B ph.	C ph.	
63	157 158	6	H-3	3 phase	9000	+ 92%	+ 12%	— 80%	10500		12450	Taken to show retardation of turbine. See Fig. 28.
64	159 160	6	"	"	9000	— 87%	+ 87%	0%	10500		13000	ditto
65	161	6	"	"	9000						8770	Wave forms.
66	164	6	"	"	9000	0%	— 87%	+ 87%	12600	12400		ditto
67	165 166	"	"	"	9000				9240	5650	11700	ditto.

Digitized by Google

stat is 85 per cent and with neutral rheostat 125 per cent. This shows that while the neutral rheostat greatly lowers the current there is at the same time a greater pressure rise.

4. DURATION OF THE TRANSIENT PHENOMENA INCIDENT TO THE SHORT CIRCUIT UNDER CONDITIONS 1, 2 AND 3

A number of tests were made in which the oil switch was kept closed for several seconds to determine the duration of the transient phenomena. In Fig. 28 are shown the traces of various currents and pressures, and a time wave taken from the 25-cycle system is added for reference. The retardation of the



Trace No. 1—*A C* generator delta pressure; scale 17,600 volts per in.
2—Generator field pressure; scale 87 volts per in.
3—Generator field current; scale 2,800 amperes per in.
4—Drop across *B* phase reactance coil; scale 7,100 volts per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 19.—Oscillograms of a *B* to ground short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

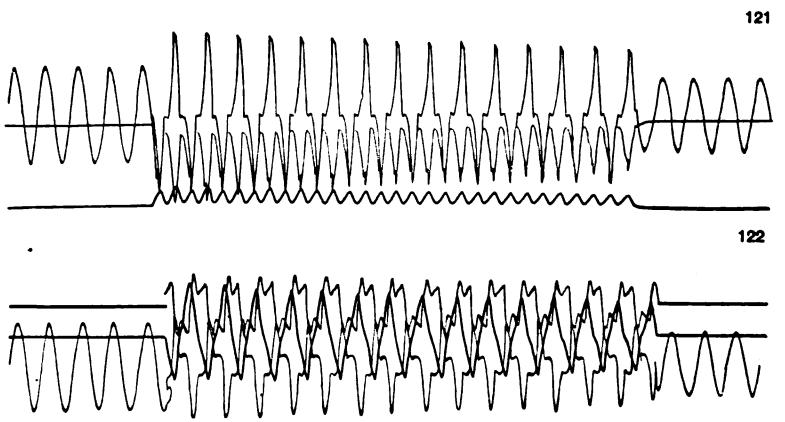
turbine, as previously mentioned, is shown to be approximately $\frac{1}{4}$ of a cycle in five seconds and the current reaches a constant value in about two seconds. The difference in the rate of decrease of amplitude of the first four cycles of trace No. 1 as compared to this decrease in amplitude of subsequent cycles shows clearly the effect of the field and the armature transients.

5. THE EFFECT ON THE GENERATOR OF THESE SHORT CIRCUIT CURRENTS

A careful examination was made of the generator after each series of tests but no effect whatever could be detected. At the

Digitized by Google

instant of short circuit in many cases a flash was seen within the generator. This was caused by the volatilized parts of the carbon brushes at the collector rings of the field circuit, and also by the induction of very large eddy currents in the field core. Trace No. 3 in Fig. 28 shows the variation in field current during the short circuit. This current may rise as high as 3,500 amperes due to induction from the armature circuit. The normal excitation at full load and unity power factor is 400 amperes. It is apparent from the above that the insertion of the 6 per cent coils renders the turbo-generator practically immune against failure due to the stresses incident to short circuits beyond the reac tances.



Trace No. 1—*A C* generator delta pressure; scale 18,100 volts per in.
2—Generator field pressure; scale 144 volts per in.
3—Generator field current; scale 2,800 amperes per in.
4—Drop across *B* phase reactance coil; scale 7,100 volts per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; 18,100 volts per in.

FIG. 20.—Oscillograms of a *B* to ground short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

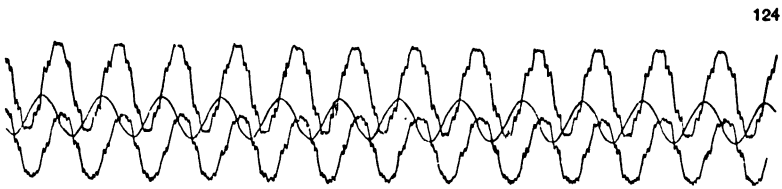
6. THE BEHAVIOR OF THE REACTANCE COILS

Early in the tests large iron nails were placed on the floor near the reactances to indicate the strength of the field at the time of short circuit. In test No. 23 one of these nails about two feet distant from the lower turn was drawn into the B phase coil.

A full load run was made to determine the heating of the coils and pieces of brass bar, copper and iron were placed near them. The generator was short circuited through the coils and with a current of 770 amperes a constant temperature was reached

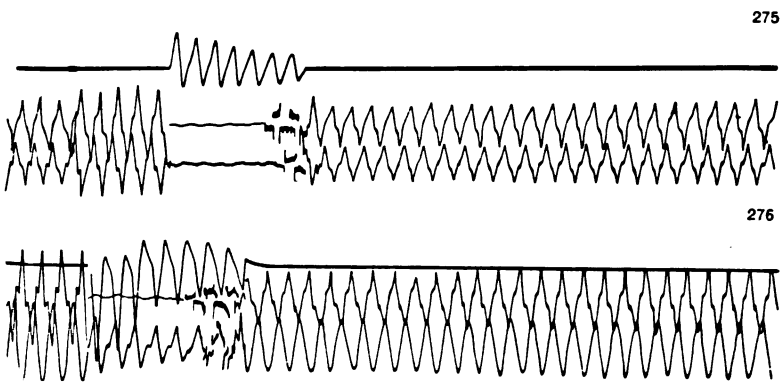
Digitized by Google

at the end of five hours. During this run the oscillogram of Fig. 21 was obtained. The tests showed that there is practically no heating in brass or copper placed near the coils. Iron bars 1 by $\frac{3}{4}$ in. in section forming a framework of an iron screen showed a temperature rise of 24 deg. cent. when placed within 12 in. of the coils.



Trace No. 1—Drop across *A* phase reactance coil, 3.8 volts.
2—*A* phase generator current, 768 amperes.
3—*A B* generator delta pressure, 576 volts.

FIG. 21.—Oscillograms showing wave forms of short circuit with full load current through external 6 per cent reactance on a three-phase short



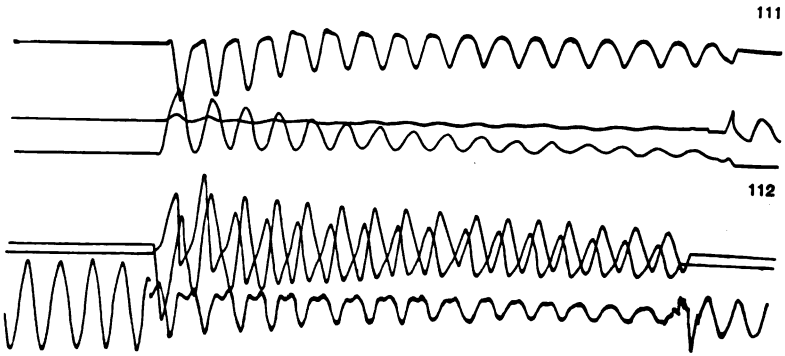
Trace No. 1—*C* phase generator current; scale 17,000 amperes per in.
2—Across *B* phase oil switch break; scale 16,000 volts per in.
3—Across *C* phase oil switch break; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—Across *A* phase oil switch break; scale 11,000 volts per in.
6—*A B* generator delta pressure; scale 18,000 volts per in.

FIG. 22.—Oscillograms showing three-phase short circuit with an external reactance of 6 per cent at 8,000 volts generator delta pressure

Various devices were applied to record possible movement of the coils but no such movement was detected. In the latter part of the tests the heavy braces at the top were disconnected but even with this support removed the coils showed no tendency to move.

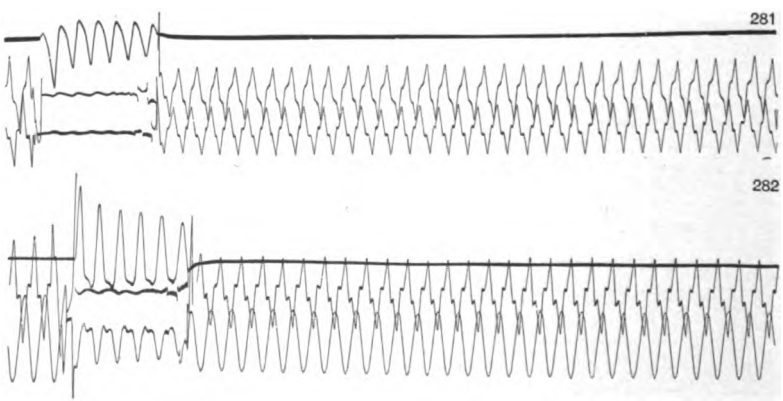
The magnetic pull due to the field was tested by holding a

Digitized by Google



Trace No. 1—*C* phase generator current; scale 14,100 amperes per in.
2—Across *A* phase oil switch break, generator side; scale 10,500 volts per in.
3—Generator field current; scale 2,800 amperes per in.
4—*A* phase generator current; scale 9,560 amperes per in.
5—*B* phase generator current; scale 11,300 amperes per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 23.—Oscillograms of a three-phase grounded short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure



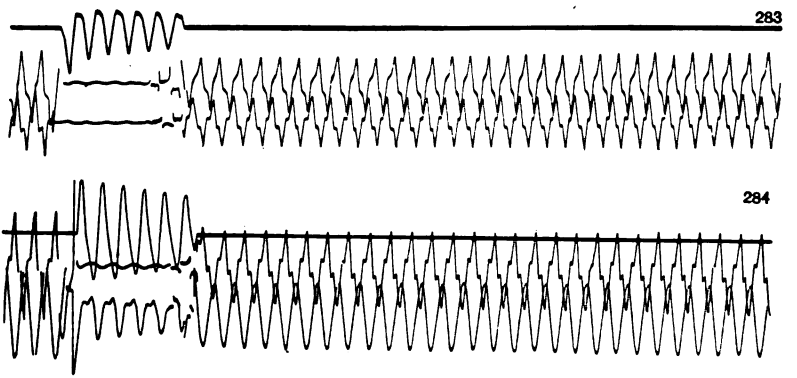
Trace No. 1—*C* phase generator current; scale 17,000 amperes per in.
2—Across *B* phase oil switch break; scale 16,000 volts per in.
3—Across *C* phase oil switch break; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—Across *A* phase oil switch break; scale 11,000 volts per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 24.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

Digitized by Google

sheet of iron screen 30 in. from one of the coils at time of short circuit. The screen was arranged to stay in position by means of a light string held by an observer, but not the slightest pull could be detected.

No pressure rises across the end turns of the coils were found. As already mentioned in the first paragraph of series No. 3, tests the maximum pressure across the coils occurred in the last half of the first cycle. The maximum voltage across a coil was found to be 7,850 volts. The maximum current during the same cycle was 11,700 amperes. On the assumption that the maximum drop occurred when the value of the current was



Trace No. 1—*C* phase generator current; scale 17,000 amperes per in.
2—Across *B* phase oil switch break; scale 16,000 volts per in.
3—Across *C* phase oil switch break; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—Across *A* phase oil switch break; scale 11,000 volts per in.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 25.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

9,000 amperes, the rate of change of the current would be

$$\frac{di}{dt} = \frac{e - iR}{L} = \frac{7850 - 670}{0.0027} = 2{,}660{,}000 \text{ amperes per second.}$$

7. THE EFFECT OF THE INSTALLATION OF REACTANCE COILS ON THE STABILITY OF THE SYSTEM

The stability of the system during cable breakdowns depends primarily on two things; first, steadiness of voltage, and second, steadiness of speed. The use of the reactances reduces the torque on the generators to such a point that the speed is not materially affected even by short circuits on the bus. This is

Digitized by Google

TABLE V

Test No.	Oscillograms	Per cent external reactance	Oil switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
49	125 126	6	H-3	3 ϕ with load	9000	— 93%	+ 77%	— 18%	3850 11000	Substation Generator		Generator carrying 5 substa. load of 1340 kw. not connected to system. See Fig. 29.
50	127 128	6	"	"	9000	+ 87%	0%	— 87%	3500 11000	Substation Generator		Gen. carrying 5 substa. load of 770 kw. not connected.
51	132	6	"	*A B* with load	9000	+ 59%	— 49%	— 99%	12900	Generator		Gen. carrying 5 substa. load of 650 kw. not connected.
52	129 130	6	"	*A* ϕ to gr. with load	9000	+ 58%	— 41%	— 99%	2550 14800	Substation Generator		ditto.
97	229 230	6	"	"	9000	100%	+ 50%	— 50%	8180 8000 220	Total Generator Substation		Generator carrying Market St. rotary running idle.
98	232	6	"	"	9000	— 62%	+ 98%	+ 37%	13100 360	Generator Substation		ditto. See Fig. 30.
99	233 234	6	"	"	9000	— 55%	+ 99%	+ 45%	13600 12200 360	Total Generator Substation		ditto. See Fig. 31.
100	235 236	6	"	"	9000	+ 72%	— 24%	— 96%	11900 11900 530	Total Generator Substation		Generator carrying Market St. rotary connected to D. C. system. See Fig. 32.
102	237 238	6	"	*A* ϕ to ground	9000	+ 98%	+ 34%	— 63%	9000			
103	239 240	6	"	*A* ϕ to grd. with load	9000	100%	+ 50%	— 50%	9000 8260 550	Total Generator Substation		Generator carrying split-pole rotary running idle.
104	241 242	6	"	"	9000	100%	+ 50%	— 50%	9000 8000 560	Total Generator Substation		ditto. See Fig. 33.
105	243 244	6	"	"	9000	100%	+ 50%	— 50%	9000 8740 560	Total Generator Substation		Generator carrying split-pole rotary connected to d. c. system. See Fig. 34.
106	245 246	6	"	"	9000	+ 70%	— 27%	— 97%	14400 12700 1130	Total Generator Substation		Generator carrying 2000 kw. frequency changer. See Fig. 35.

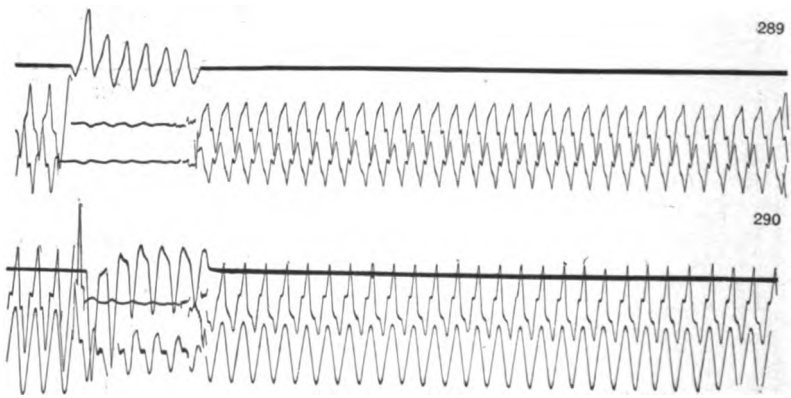
Digitized by Google

TABLE V. (*Continued.*)

Test No.	Oscillograms	Per cent external reactance	Ol switch	Kind of short circuit	Gen. delta pressure	Y voltages at instant before short circuit			Maximum currents			Remarks
						A ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph.	*B* ph.	*C* ph.	
107	247 248	6	*H*–3	*A* ϕ to grd. with load	9000	100%	+ 50%	— 50%	9360 8000 1020	Total Generator Substation		ditto.
110	255 256	6	"	"	9000	+ 90%	+ 8%	— 83%	10500	15800		
111	257 258	6	"	"	9000	+ 83%	— 7%	— 89%	10800	14800		
151	259 260	6	"	"	9000	+ 90%	+ 8%	— 82%	10500 9400 470	Total Generator Substation		Generator carrying Market St. rotary connected to d.c. system.
155	261 262	6	"	"	9000	+ 98%	+ 34%	— 64%	8500 8920	Total Generator		ditto.
156	263 264	6	"	"	9000	100%	+ 50%	+ 50%	10500 10300 380	Total Generator Substation		ditto. See Fig. 36.
157	265 266	6	"	"	9000	+ 90%	+ 8%	— 63%	10700 10500 330	Total Generator Substation		ditto. See Fig. 37.
158	267 268	6	"	"	9000	+ 98%	+ 34%	— 64%	8500 8460 340	Total Generator Substation		ditto.
In the four following tests a 2½ ohm resistance was inserted to the neutral connection to ground												
197	327 328	6	"	*A* ϕ to grd. with load	9000	+ 65%	— 33%	— 98%	2550 2350 150	Total Generator Substation		Generator carrying standard rotary connected to d. c. system.
198	329 330	6	"	"	9000	100%	+ 50%	— 50%	2550 2350 150	Total Generator Substation		ditto. See Fig. 38.
199	331 332	6	"	"	9000	+ 92%	+ 12%	— 80%	2450 2280 130	Total Generator Substation		Generator carrying standard rotary connected to d.c. system. See Fig. 39.
200	333 334	6	"	"	9000	+ 92%	+ 12%	— 80%	2580 2280 140	Total Generator Substation		ditto.

Digitized by Google

shown clearly by the small retardation of the generator, shown in Fig. 28 previously referred to. The voltage on the bus, however, is directly dependent on the resistance of the short circuit from the bus to the fault and back, as well as on the nature of the fault, and is, therefore, practically independent of the reactances. If then the voltage drops to such a point that the synchronous apparatus connected to the system feeds back sufficient energy to actuate the overload relays on the substation units, the oil switches on these units will be opened, *i.e.*, the load will drop off. If the bus voltage does not reach a very low point or if the overload relays in the substation are provided with



Trace No. 1—*C* phase generator current; scale 17,000 amperes per in.
2—Across *B* phase oil switch break; scale 16,000 volts per in.
3—Across *C* phase oil switch break; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—Across *A* phase oil switch break; 11,000 volts per in.
6—*A* phase to neutral generator pressure; scale 10,900 volts per in.

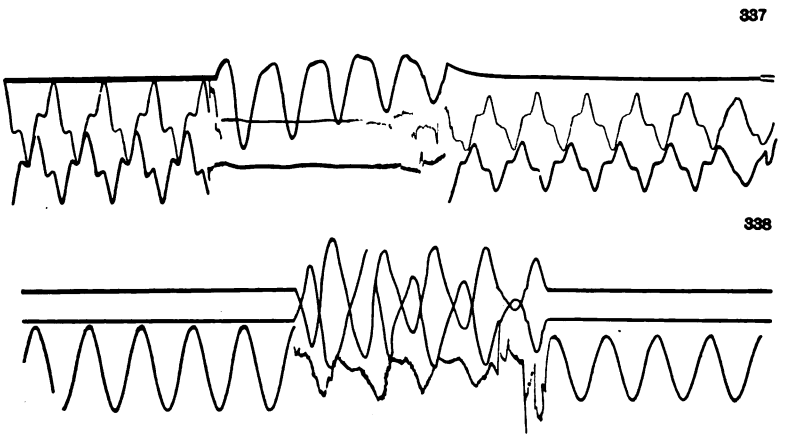
FIG. 26.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator delta pressure

fixed time elements which will make them inoperative, short of, say one second, then the reactance in the generator circuit will by the phase displacement of the current cause the synchronizing component of the current to be greater, thereby making the system more stable. This is illustrated in Fig. 40 where OA represents the generator e.m.f., OB the counter e.m.f. of the substation unit, and OC the resultant e.m.f. causing a cross current to flow. This cross current with only a small amount of reactance in the circuit has the direction OI_1, lagging behind OC by angle α. This angle is increased to α', the current vector then being OI_3, when the reactance in the circuit is in-

Digitized by Google

creased as by the installation of generator reactances; the greater the reactance, the greater will the angle α be. The component of I in phase with the negative vector of OB, or OB', is the energy or synchronizing current, and the increase in this value from OI_2 to OI_4 due to increase of angle α is clearly seen. All angles and the current vectors are purposely very much exaggerated for sake of clearness.

Another advantage gained by having the reactances in the armature leads lies in the fact that with lowering of the bus pressure, as by a short circuit, the generator voltage is not reduced



Trace No. 1—*C* phase generator current, scale 11,700 amperes per in.
2—Across *B* phase oil switch break; scale 16,000 volts per in.
3—Across *C* phase oil switch break, scale 18,700 volts per in.
4—*A* phase generator current; regular transformer, scale 9,400 amperes per in.
5—*A* phase generator current from special current transformer, scale 9,700 amperes per in.
6—*A* phase to neutral generator pressure, scale 10,900 volts per in.

FIG. 27.—Oscillograms of a three-phase short circuit with 6 per cent reactance at 9,000 volts generator delta pressure

by the same amount due to the drop in the reactances themselves. Normal pressure is thus restored more quickly.

Various substation units of the operating system were connected to the turbo-generator under test and short circuits were then produced to note the behavior of these substation units.

It was, of course, impossible to exactly reproduce conditions of faults in the system therefore a definite comparison of the action with and without reactances cannot be made. However, from the test results the stability of the various types of substation units can be determined. The desirability of some minor changes in substation relay settings is also indicated.

Digitized by Google

TABLE VI
PRESSURE RISES AT GENERATOR AND LOAD BUS

Test No.	Oscillograms	Per cent reactance	Kind of short circuit	Gen. delta pressure before short circuit	Generator pressure rises				Load bus pressure rises						Remarks
					Closing switch		Opening switch		Closing switch			Opening switch			
					Phase	Per cent normal	Phase	Per cent normal	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	
97	229	6	*A* ϕ to gr. with load	9000					None	46%	62%	None	18%	13%	Generator carrying Market St. rotary running idle.
99	233	6	"	9000					"	83%	72%	"	5%	85%	ditto
100	235	6	"	9000					"	53%	61%	"	15%	7%	Generator carrying Market St. rotary connected to d.c. system.
102	237	6	*A* ϕ to ground	9000					"	60%	60%	"	40%	10%	Tests made without substation load.
103	239	6	*A* ϕ to gr. with load	9000					"	57%	63%	"	25%	8%	Generator carrying split pole rotary running idle.
104	241	6	"	9000					"	57%	59%	"	30%	10%	ditto
105	243	6	"	9000					"	60%	42%	"	24%	None	Generator carrying split pole rotary connected to d.c. system.
106	245	6	"	9000					"	75%	74%	"	45%	23%	Generator carrying 2000 kw. frequency changer.
107	247	6	"	9000					"	41%	37%	"	30%	5%	ditto
109	252	6	3 phase	9000	*A B*	None	*A B*	136%							
151	259	6	*A* ϕ to gr. with load	9000					"	59%	56%	"	16%	?	Generator carrying Market St. rotary connected to d.c. system
155	261	6	"	9000					"	80%	94%	"	22%	53%	ditto

Digitized by Google

TABLE VI (*Continued.*)
PRESSURE RISES AT GENERATOR AND LOAD BUS

Test No.	Oscillograms	Per cent reactance	Kind of short circuit	Gen. delta pressure before short circuit	Generator pressure rises				Load bus pressure rises						Remarks
					Closing switch		Opening switch		Closing switch			Opening switch			
					Phase	Per cent normal	Phase	Per cent normal	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	*A* ph. to ±	*B* ph. to ±	*C* ph. to ±	
156	263	6	*A* ϕ to gr. with load	9000					None	74%	83%	None	40%	67%	generator carrying standard rotary connected to d.c. system.
157	265	6	"	"					"	70%	73%	"	36%	62%	ditto
158	267	6	"	"					"	70%	83%	"	36%	48%	ditto
160	272	6	3 phase	7000	*A B*	30%	*A B*	7%							Defective oil switch
161	274	6	"	5000	*A B*	None	*A B*	40%							ditto
164	278	6	"	8000	*A B*	93%	*A B*	None							ditto
167	282	6	"	9000	*A B*	46%	*A B*	"							ditto
168	284	6	"	9000	*A B*	43%	*A B*	25%							ditto
169	286	6	"	8000	*A B*	None	*A B*	?							ditto
170	298	6	"	9000	*A B*	Over 70%	*A B*	None							ditto
184	310	6	*A B* through bomb fuse		*A B*	20%									Pressure rise on fuse test.
172	290	6	3 ϕ	9000	*A B*	62%	*A B*	None							Defective oil switch.
In the following tests a 2½ ohm resistance was inserted in the neutral to ground															
197	327	6	*A* ϕ to gr.	9000					None	104%	20%	None	113%	20%	Generator carrying Market St. rotary connected to d.c. system.
198	329	6	"	"					"	113%	35%	"	113%	35%	ditto
199	331	6	"	"					"	120%	35%	"	120%	35%	ditto
200	333	6	"	"					"	126%	33%	"	126%	33%	ditto

Digitized by Google

Because of the impossibility of definite and complete conclusion it was thought advisable to give the data of these tests in some detail so that any who may care to do so can study them.

Tests with a Group of Substation Units. In this series of tests five substation units in as many substations were used. The data on the lines, units and relay settings concerned being as follows:

Substation	Line			Unit		
	No.	Size	Length	No.	Capacity	Class
Market St..	58	4/0	17900′	3	1000 kw.	Standard converter 275 v. 214 r.p.m.
Indiana St..	87	4/0	24600′	1	1000 kw.	Split pole converter 270 v. 300 r.p.m.
Lake View..	133	250,000 cm.	35900′	4	1000 kw.	25/60 cy. frequency ch.
42nd St....	138	4/0				
	331	250,000 cm.	40500′	5	2000 kw.	Standard converter 600 v.d.c.
	332	250,000 cm.				
Grand Ave..	90	250,000 cm.	42500′	1	2000 kw.	Standard converter 600 v.d.c.

Relay settings

Substation	Unit			Substation line switch			Generating station line switch		
	Amperes			Amperes			Amperes		
	Core	2 sec.	Inst.	Core	4 sec.	Inst.	Core	2 sec.	Inst.
Market St.....	155	233	310	No relays			400	560	750
Indiana St.....	155	233	310	"			400	560	750
Lake View.....	155	233	310	"			480	670	900
		4 sec.							
42nd Ave.....	240	256	640	300	384	766	400	560	750
		2 sec.							
Grand Ave.....	310	465	620			650	480	670	900
Fault.....	(Relay controlling short circuiting switch)								2000

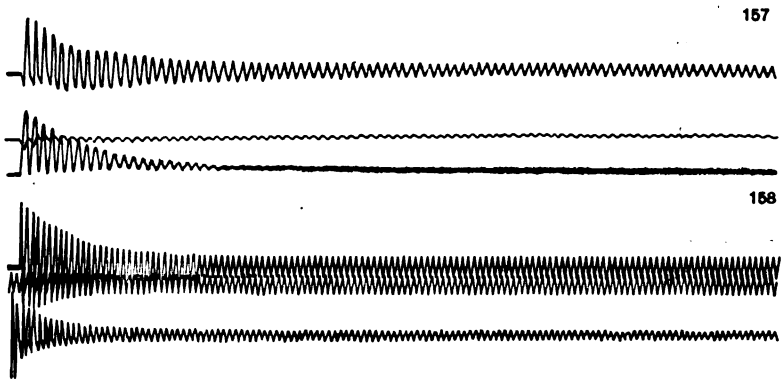
Under "relay settings" are given the current values for which the apparatus was adjusted at the last periodical check. The primary amperes are shown which are required to raise the core without time element attachments and primary amperes with time element attachments to raise the core in two seconds and instantaneously. In all substation tests the same units and relay settings were used unless otherwise mentioned.

In all four tests the five units were connected only to the 25 cycle system and there was, therefore, no possible back feed

Digitized by Google

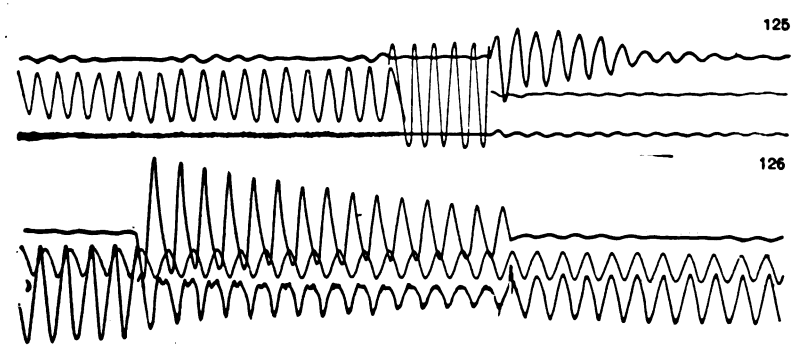
other than that due to the stored energy in the rotating members.

In Test No. 49, Fig. 29, all substation units opened the alternating current switches; Market Street in about four seconds, the



Trace No. 1—*C* phase generator current; scale 14,100 amperes per in.
2—Across *A* phase oil switch break generator side; scale 5,500 volts per in.
3—Generator field current; scale 2,800 amperes per in.
4—*A* phase generator current; scale 9,560 amperes per in
5—Time reference wave from 25 cycle system.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 28.—Oscillograms of a three-phase short circuit with an external reactance of 6 per cent at 9,000 volts generator pressure to show retardation of turbine.



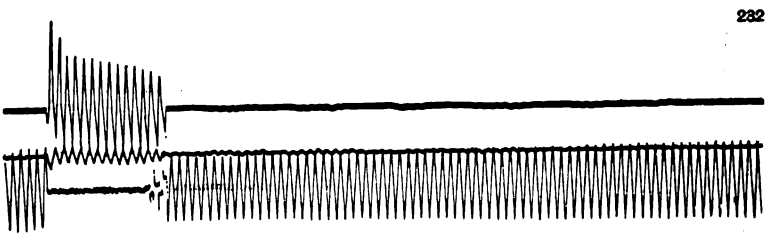
Trace No. 1—*A* phase substation current; scale 5,660 amperes per in.
2—*A B* line bus pressure, scale 17,300 volts per in.
3—Defective connection.
4—*A* phase generator current; scale 9,560 amperes per in.
5—Time reference wave from 25 cycle system.
6—*A B* generator delta pressure; scale 18,100 volts per in.

FIG. 29.—Oscillograms showing the effect of 6 per cent reactance coils on the operation of substations during a three-phase short circuit on bus

others instantaneously. In Test No. 50, the Market Street unit stayed in eight seconds and would presumably have so continued but as the unit showed some sparking on the commu-

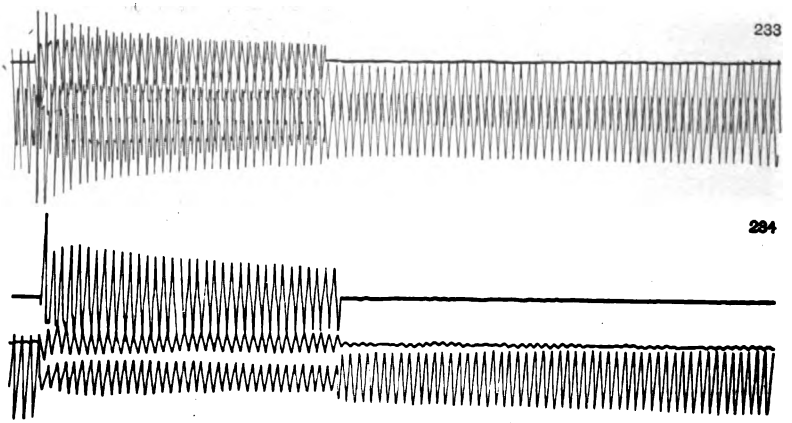
Digitized by Google

tator it was disconnected by the operator. All other units opened the alternating current switches on reverse overload. In Test No. 51 on a single-phase short circuit between *A* and *B*



Trace No. 1—*A* phase generator; scale 9,400 amperes per in.
2—*A* phase sub-station current, scale 2,000 amperes per in.
3—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 30.—Oscillogram showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 400:1 current transformer controlling *H*3 short circuiting switch.



Trace No. 1—*A* phase current through short, scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 9,800 volts per in.
3—*C* phase to neutral line bus pressure; scale 11,300 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase sub-station current; scale 17,20 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 31.—Oscillogram showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Inverse time element relay on 400:1 current transformer controlling *H*3 short circuiting switch

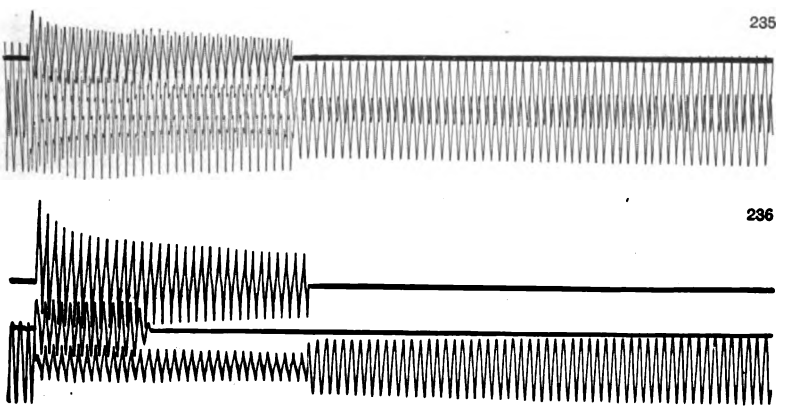
phases, the Market Street unit stayed in, but the others again opened the alternating current unit switches on reverse overload. In Test No. 52 all the units stayed in except Indiana Street and even this unit hung on for about one second.

Digitized by Google

In none of the tests were the line switches in the generating station opened.

Tests with Single Substation Units of Various Types. This series of tests was started with the idea of checking the operation of the individual units used in Tests No. 49 to 52 inclusive, thus eliminating any effect of cross current between substations.

Standard Converter with Induction Regulator. The first unit to be tried was No. 3 synchronous converter at the Market Street substation and for tests No. 97 and 98, Fig. 30, the H-3



Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 9,800 volts per in.
3—*C* phase to neutral line bus pressure; scale 11,300 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

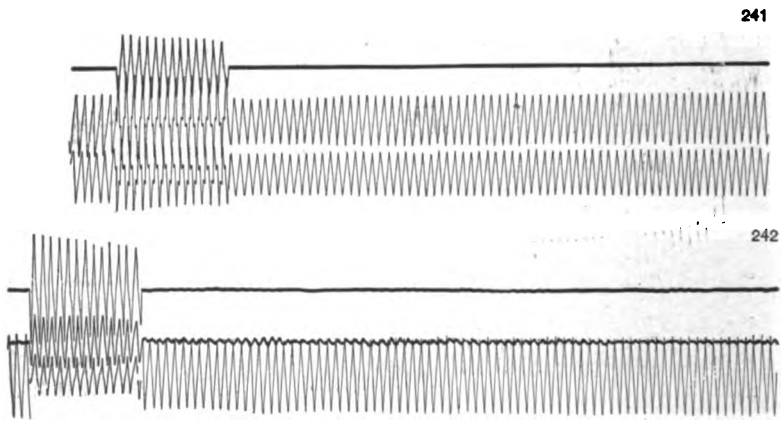
FIG. 32.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Inverse time element relay on 400:1 current trans former controlling *H*3 short circuiting switch.

short circuiting switch at Fisk Street was controlled by the same instantaneous relay used in the preceding tests connected to a 400 to 1 current transformer. In both tests the Market Street converter was running idle, connected only to the alternating current end, and in both tests the unit remained connected through to the line bus after the short. For Test No. 99, Fig. 31, and Test No. 100, Fig. 32, a new type of overload relay was substituted for the instantaneous relay as the control for the H-3 short circuit switch, and in Test No. 99 with the Market Street machine connected only to the alternating current end

Digitized by Google

the unit remained in synchronism. In Test No. 100, Fig. 32, however, when the Market Street unit was connected to the direct current bus in parallel with converters No. 2 and 3 and a storage battery, the machine tripped out on both the alternating current and direct current sides. At the instant of short circuit in this last test the battery ammeter showed a current of 10,000 amperes and synchronous converter No. 2 ammeter about 2000 amperes.

For these and all subsequent tests the short circuit was made



Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

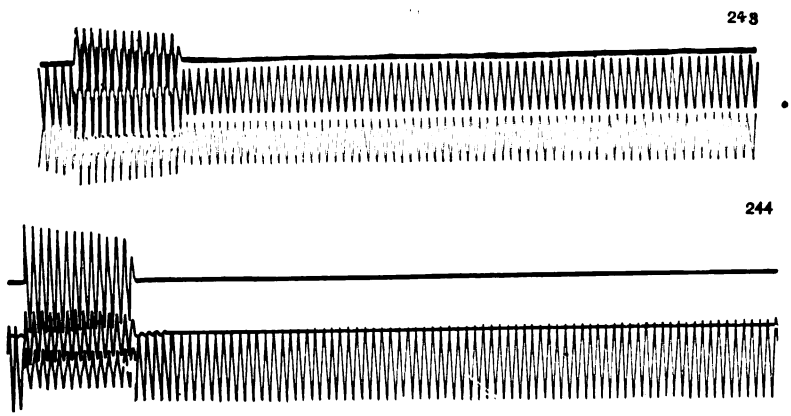
FIG. 33.—Oscillograms showing effect of reactance coils on the operation of a split pole converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch

at the end of one phase of a 200-ft. length of 250,000-cir. mil cable through an artificial fault to ground. This fault consisted of two copper plates clamped on either side of an asbestos board, through which a small hole was drilled. The two coppers represented the conductor and lead sheath of the cable while the asbestos board replaced the insulation. In this series of four tests a short length of No. 36 *I a I a* wire was connected between plates through the hole in the asbestos to start the short circuit, but in Test No. 102 and the remaining trials of substation operation the fuse wire was omitted as it was found that

Digitized by Google

the artificial fault broke down gradually without previous fusing, thus more nearly duplicating actual fault conditions.

Test No. 151 is a repetition of test No. 100 using the instantaneous relay connected to a 60 to 1 current transformer to control the H-3 short-circuiting switch, as it was hoped that under these conditions the unit might remain connected. At the instant of short, however, the direct current circuit breakers opened on reverse current and all three phases of the unit overload relays tripped out the oil switches.

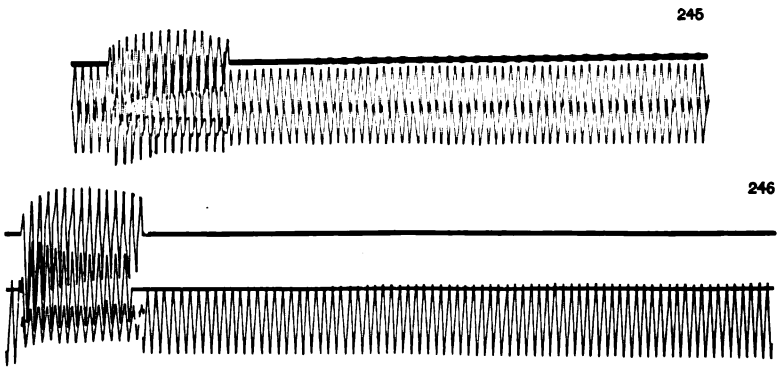


Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 34.—Oscillograms showing effect of reactance coils on the operation of a split pole converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch.

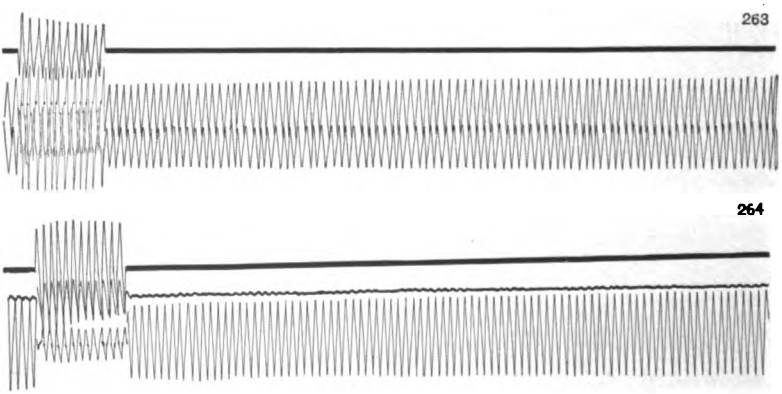
Tests No. 155, 156, 157 and 158 were made with a new type of inverse current relay previously used in certain of the former tests for control of the alternating current short-circuiting switch. This relay was installed at Market Street in place of the standard relay equipment to control the alternating current unit switch. In Tests No. 155 and 156, Fig. 36, and Test No. 158 the direct current circuit breakers opened on reverse current before the relay cones raised sufficiently to trip out the oil switch and in Test No. 157, Fig. 37, the unit remained connected to both the direct current and alternating current systems.

Digitized by Google



Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 35.—Oscillograms showing effect of reactance coils on the operation of standard frequency changer during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuiting switch

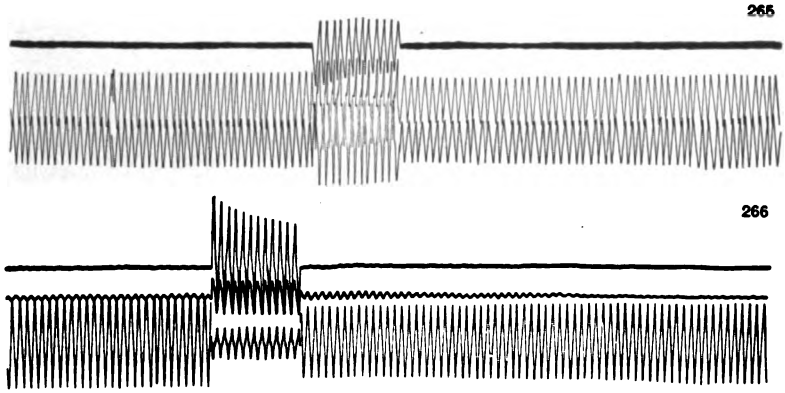


Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 36.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuit switch. Inverse time element relay controlling unit switch

Digitized by Google

In all previous operating tests the neutral of generator No. 10 was connected directly to ground, the single phase short circuit current being limited therefore only by the reactance coils. As no satisfactory operating results could be obtained under these conditions it became evident that the neutral rheostat must be retained as an essential part of the system and the present group of tests were therefore made to determine the operating results when rheostat was included in the connection to short circuit. The unit at the Market Street substation which had previously been used was not available and a similar unit at the



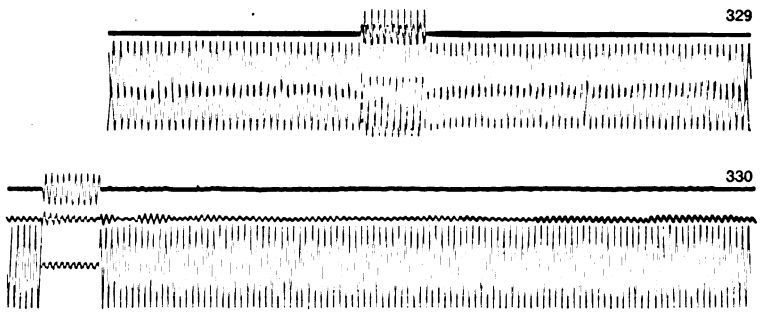
Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current; scale 9,400 amperes per in.
5—*A* phase substation current; scale 1,270 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 37.—Oscillograms showing effect of reactance coils on the operation of standard synchronous converter during a phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuiting switch. Inverse time element relay, controlling unit switch

Jackson Boulevard substation was therefore used. In Tests No. 197 and 198, Fig. 38, the alternating current switch of this unit was controlled by the new type reverse current relay, while in Tests No. 199, Fig. 39, and Test No. 200 the alternating current switch control was reconnected to the standard relay equipment. In all four tests although the unit was connected to the direct current auxiliary bus and thence through four feeders to the direct current network, the generator neutral rheostat so limited the short circuit current that the rotary remained connected to both the alternating current and direct current systems.

Digitized by Google

Converter with Regulating Field (Split Pole). Tests No. 102, 103, 104 and 105 were made with the generator carrying the Indiana St. 1000-kw. split pole converter. In all tests the short-circuiting switch was controlled by the instantaneous relay, as the split pole converter opened on the alternating current end. In Tests No. 103 and 104, Fig. 33, when running disconnected from the direct current end, and in Test No. 105, Fig. 34, when running on the direct current auxiliary bus connected to the direct current network through three feeders. It was, therefore, not necessary to make further tests with the time element control of the short-circuit switch.



Trace No. 1—*A* phase current through short; scale 17,000 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current, scale 9,400 amperes per in.
5—*A* phase substation current, scale 1,000 amperes per in.
6—*A* phase to neutral line bus pressure, scale 10,900 volts per in.

FIG. 38.—Oscillograms showing the effect of reactance coils plus generator neutral rheostat on the operation of a standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling *H*3 short circuit switch. Inverse time element relay controlling unit switch

Frequency Changer Unit (9000 *Volt*, 25 *Cycle Synchronous Motor*). Tests No. 106, Fig. 35, and Test No. 107 were made with a standard 2,000-kw. frequency changer at the Hyde Park substation instead of a 1,000-kw. frequency changer at the Lake View substation used in Tests No. 49 to 52 inclusive. In both trials made with the unit connected to the 25-cycle end only, the unit oil switch opened and in Test No. 106 the line switch at Fisk Street also opened, the noise of this latter short circuit giving the observers the impression that it was very severe. No trials were made with the time limit relay as the unit was too unstable for satisfactory operation even with instantaneous control of the short circuiting switch.

Digitized by Google

The full data on lines, units and relay settings concerned in these operating tests are given in the following table:

Substation	Line			Unit		
	No.	Size	Length	No.	Capacity	Class
Hyde Park..	144	4/0	32,700 ft.	2	2000 kw.	25/60 F. C. 300 r.p.m. 9000/4000 volts.
Jackson Blvd.....	9 130	4/0 4/0	5,500 ft. 14,400 ft.	2	1000 kw.	Standard converter 250 volts, 214 r.p.m.

Substation	Specified relay settings					
	Unit amperes			Generating station Line-switch amps.		
	Core	2 sec.	Inst.	Core	2 sec.	Inst.
Hyde Park.....	310	465	620	400	560	750
Jackson Blvd...	155	233	310	400	560	750

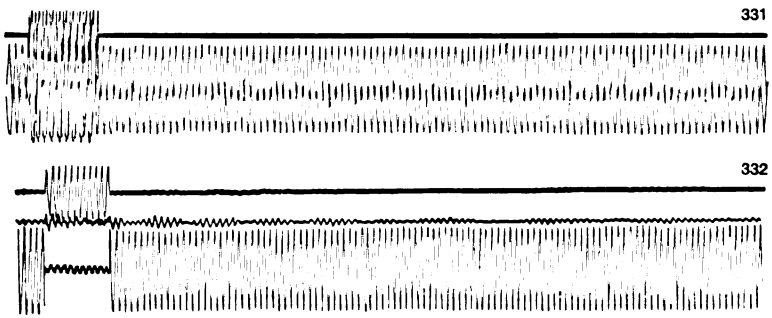
General Discussion of Results

The insertion of 6 per cent reactance reduces the instantaneous current on a three phase short from 27 to 14.5 times the full load current. In addition to this, account must be taken of the phase relation of this current to the voltage producing it. With the reactances in, the total resistance of the circuit was 0.033 ohms. The maximum Y pressure is 7350 volts, the impedance of the entire circuit including the effect of armature reaction, self-induction of the winding and the external reactance is $\frac{7350 \text{ volts}}{15{,}800 \text{ amperes}}$ or 0.46 ohms, therefore, the power factor at this current is apparently $\frac{0.033}{0.46}$ or 7.2 per cent. Without external reactance the resistance of the total circuit is that of the armature winding alone, or 0.025 ohms. The impedance of the armature circuit from test equals $\frac{7350 \text{ volts}}{29{,}000 \text{ amperes}}$ or 0.25 ohms per phase therefore, the power factor of the current is apparently 10 per cent. As this armature circuit is embedded in iron there must be a very appreciable hysteresis loss which is true energy. The actual power factors are therefore probably several times the values given above. The decrease in power factor due to the

Digitized by Google

reactances is in greater ratio than 10 to 7.2 (from above values) as the hysteresis component of the energy is also smaller with the lesser current resulting from the insertion of reactances. The energy due to a sudden short circuit is reduced in proportion to the power component of the current, therefore, the shock on the generator will be a great deal less with reactances than without reactances. The strains on the coils, however, are directly proportional to the square of the current and therefore would be over three times as great without external reactance as with such reactance.

If the two machines are thrown together 180 deg. out of phase



Trace No. 1—*A* phase current through short; scale 6,450 amperes per in.
2—*B* phase to neutral line bus pressure; scale 16,000 volts per in.
3—*C* phase to neutral line bus pressure; scale 18,700 volts per in.
4—*A* phase generator current; scale 5,700 amperes per in.
5—*A* phase substation current, scale 1,000 amperes per in.
6—*A* phase to neutral line bus pressure; scale 10,900 volts per in.

FIG. 39.—Oscillograms showing the effect of reactance coils plus generator neutral rheostat on the operation of a standard synchronous converter during *A* phase to ground short circuit on bus. Instantaneous relay on 60:1 current transformer controlling short circuit switch, Regular relay controlling unit switch

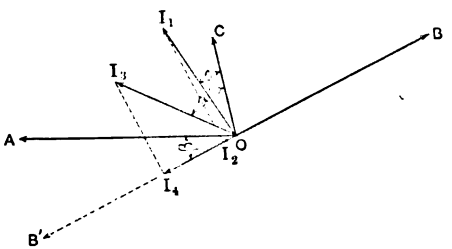
the e.m.f. in the entire circuit is doubled as are also the resistances and reactances. Therefore the armature current is the same as if the machines were short circuited at their terminals, that is, a possible maximum of 15,800 amperes. If the machines are thrown into a circuit partly out of step the maximum current is equal to the short circuit current multiplied by the sine of half the angle of phase displacement. At Fisk Street five machines are run in parallel during the peak. Where four machines are feeding a bus and the fifth is thrown in 180 deg. out of step the total e.m.f. is doubled while the resistances and reactances are increased only 1.25 per cent. This means that there

Digitized by Google

would flow an instantaneous current 60 per cent greater than the short circuit current of the machines. With 6 per cent reactance in series with each generator this would amount to 25,300 amperes. Without external reactance this would amount to 46,000 amperes assuming no saturation.

When external reactances are used, the drop across the reactance of the incoming machine might be as high as 13,000 volts. It is, therefore, doubtful if the reactance as designed would protect the generator entirely in case of very bad synchronizing. The 25,300 amperes is 60 per cent more current than on any short circuit and some of the short circuits while they did not harm the turbine, resulted in a fairly severe shock.

If five turbo-generators are running in parallel and an internal



O A—Generator e.m.f.
O B—Counter e.m.f. of substation unit.
O B'—Negative vector of *O B*
O C—Resultant e.m.f. (of *O A* and *O B*) causing cross current to flow
O I—Cross current with small amount of reactance
O I—Active or synchronizing component of *O I*
O I—Cross current with larger amount of reactance in the circuit
O I—Active or synchronizing component of *O I*

FIG. 40

short circuit occurs on one of them it can be assumed its voltage drops to zero. The other four machines will then feed into it. The reactances in the generator leads and the other four sets of reactances will limit the current from the busses. Figuring the generator reactances as 4 per cent and the external reactance as 6 per cent the amount of reactance to limit the current will be 6 per cent $+\frac{1}{4}$ of 10 per cent or $8\frac{1}{2}$ per cent. The pressure across the terminals of the defective machine would be 9000 volts. Therefore the current that would flow would be 100/85 of 15,800 or about 18,600 amperes.

In order to find the maximum instantaneous kilowatts of turbo-generator No. 10 during short circuit, curves of the armature and field current were taken from oscillograms No. 317 and

Digitized by Google

No. 318 and drawn to scale. These are shown in Figs. 41 to 44 inclusive. The curves show the armature and field currents for the first cycle during a three phase short circuit with 6 per cent external reactance at 9000 volts generator delta pressure.

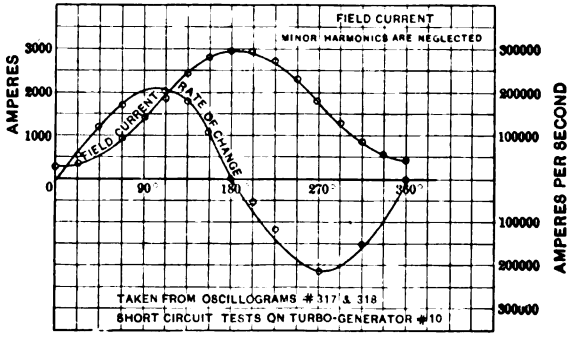


FIG. 41.—Curves showing wave forms and rate of change during a three-phase short circuit with 6 per cent reactance at 9,000 volts

Neglecting other losses, the addition of the $I^2 R$ values gives the total power generated.

The resistance of the entire circuit per phase included armature, reactance and oil switches, as measured was 0.033 ohms.

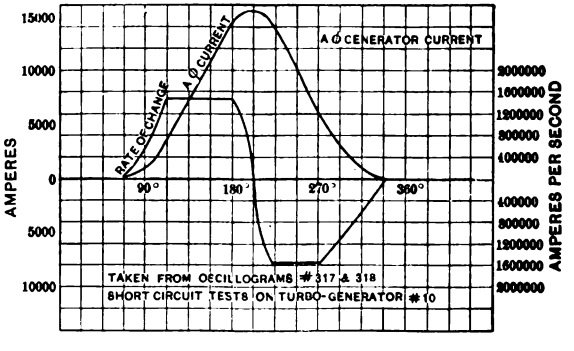


FIG. 42.—Curves showing wave forms and rate of change during a three-phase short circuit with 6 per cent reactance at 9,000 volts

Oscillograms show, however, considerable drop across the oil switch used for short circuiting. This drop from a number of oscillograms corresponded to a resistance of 0.1 to 0.18 ohms. This value is not very accurate on account of the small deflection

Digitized by Google

on the oscillograms measured. The oscillograms also show that this drop is not always directly in phase with the current. The resistance of the generator field circuit was 0.4 ohms, neglecting exciter resistance.

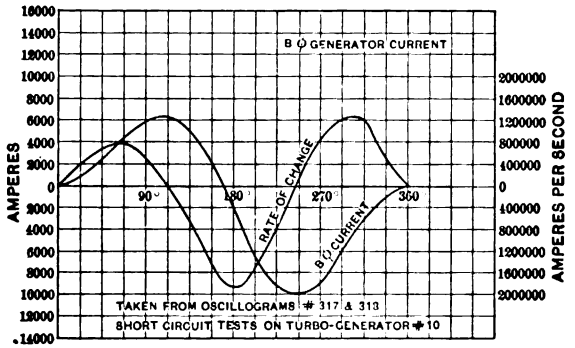


FIG. 43.—Curves showing wave forms and rate of change during three-phase delta short circuit with 6 per cent reaction of 9,000 volts

Assuming no extra resistance in the switch, the maximum instantaneous kilowatts as shown in the illustrations occurred at 190 deg. At this time the values are $A\,\phi$, 8000 kw., $B\,\phi$, 1320 kw. $C\,\phi$, 2,670 kw., field 2,720 kw., total 14,700 kw. The

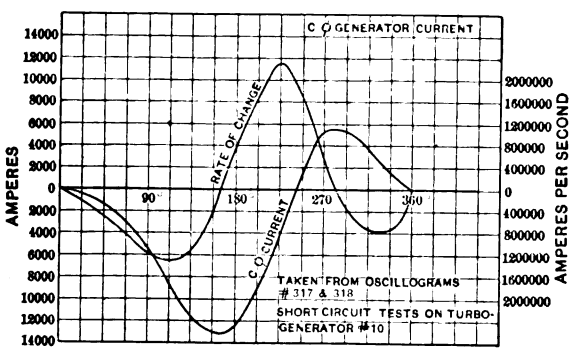


FIG. 44.—Curves showing wave form and rate of change during a three-phase delta short circuit with 6 per cent reactance at 9,000 volts

maximum full load kw. is two times maximum kilowatts of one phase or 16,000 kw. Therefore, the maximum instantaneous torque is 0.9 times the full load maximum torque. If 0.1 ohm is added for the switch, the maximum instantaneous torque be-

Digitized by Google

comes 3.6 times the full load maximum torque. This neglects the power supplied to the field by the exciter and the power losses due to the stray magnetic flux of the armature reaction.

The mean kilowatts during the first cycle as shown in the illustrations are as follows: $A\phi$ 1,940 kw., $B\phi$ 1,000 kw., $C\phi$ 1,440 kw. Field (induced only) 1,300 kw., total 5,680 kw.

The average kilowatt rating of the generator is 12,000 kw. Therefore, the average torque for the first cycle is 0.47 times full load torque. If 0.1 ohm is added for the switch, the average torque for the first cycle is 1.9 times full load torque.

A curve showing the maximum instantaneous short circuit current with various values of external reactances is given in Fig. 45.

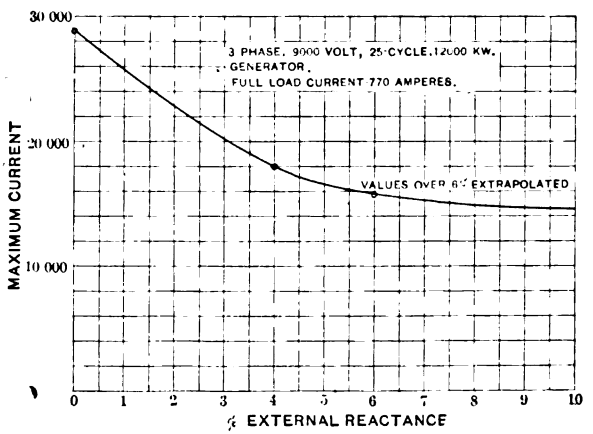


FIG. 45.—Maximum amperes on short circuit with different external reactances. Turbo-generator No. 10 at Fisk Street Station.

SUMMARY AND CONCLUSIONS

All of the preceding data and discussion can be briefly summarized in a few general conclusions, as follows:

Experience with many large capacity, high speed generators, indicates the need for reducing the possible current which may flow into a fault.

The tests indicate that the instantaneous short circuit current of these generators is actually not as high as has been thought but that this current, due to its comparatively high power factor, produces severe stresses on the generator and seriously strains the oil switches.

Digitized by Google

In order to reduce the severity of these strains and their wide spread effect in system disturbances, it is desirable to have a higher value of reactance in the generator circuit than many of these large capacity generators have been designed for. In the case of the 12,000-kw., 9000-volt, 750-rev. per min., 25-cycle units it appears that an external reactance of approximately 6 per cent is desirable. A lesser value than this does not reduce the current sufficiently and a greater value results in a very small increment of decrease. This is also true for the 6 per cent reactance with regard to the torque on the generator resulting from the short circuit.

Such reactances will limit the current to a value where it can be safely interrupted by properly designed oil switches and will keep the torque on the generator down to so low a value that even when feeding into a short circuit at the busbars there is no appreciable lessening in speed nor is the unit subjected to severe strains.

The use of the neutral rheostats at Fisk Street should be continued even after the reactances are installed as the combination of these two pieces of apparatus tends materially toward lessening the spread and severity of short circuits, which, in most cases at least, start as single-phase short circuits.

Operating experience, covering a period of about two years with reactances in connection with 5000-kw., 9000/20,000-volt transformers, shows these coils to be apparently very effective in the desired direction.

The use of reactances tends to make the operation of the system as a whole more stable and, therefore, increases the reliability of the service. The use of such coils, therefore, is apparently the solution of the most serious problems and as a result in a large measure of the extensive tests described above, engineers may now rest assured that the heavy investments already made and still to be made in power stations of great magnitude are secure, and that the safe-guarding of these very large capacity units, which have aided so materially in reducing the cost of the product, is now a definite accomplishment.

Acknowledgment is due to the various engineers engaged on the tests, to Mr. E. B. Merriam and staff, Messrs. W. A. Durgin, N. J. Conrad, R. H. Whitehead and others from the Testing Department of the Commonwealth Edison Company and especially to Messrs. Durgin and Whitehead for assistance in working out the very complete set of results which permitted a proper correlation of the data and its presentation in this paper.

Digitized by Google

BIBLIOGRAPHY

Among the papers which have been published on the subjects of short circuit currents and reactances the following will be found of value and interest.

Short Circuiting of large Electric Generators and the Resulting Forces in Armature Windings. By Miles Walker. *Electrician*, 1910, p. 882 to 935. Discussion page 937, 984, 918, 1003.

The Sudden Short Circuiting of Alternators. By F. Punga. *The Electrician*, 1906, page 765.

Beschreibung einer 5000 kw. Drehstrom-machine. By H. M. Hobart and F. Punga. *Electrische Kraftbetriebe und Bahnen*, p. 541–611.

Wechselstromgeneratoren und Transformatoren mit geringem Kurzschlusstrom. By Dr. F. Niethammer. *Electrische Kraftbetriebe und Bahnen*, 1909, p. 680.

Kurzschlusswirkungen und Aufbau von Turbogeneratoren. *Electrische Kraftbetriebe und Bahnen*, 1910, p. 541–611.

Short circuits in A. C. Transmission Networks. *Electrotech Rundschau*, October 20, 1910.

The Use of Reactance Coils in Generating Stations. P. Junkersfeld. N. E. L. W. '09. *Electrical Age*, June, 1909.

Practical Design of Reactance Coils for Turbo-Generators. A. S. Loizeaux, N. E. L. A. '09. *Electrical Age*, June, 1909.

Digitized by Google

REPORT OF THE LIBRARY COMMITTEE

FOR YEAR ENDING APRIL 30, 1911

Board of Directors American Institute of Electrical Engineers.

GENTLEMEN:—In accordance with Section 24 of the By-Laws of the Institute we beg leave to submit herewith our annual report for the year ending April 30, 1911, showing the state of the library and including the names of all donors to it.

The efforts of the committee have been directed towards the ultimate extension of the usefulness of the library to the members of the founder and associate societies and to non-members, whether resident or non-resident in New York City, and towards the harmonious, equitable and efficient administration of the joint libraries housed in the upper stories of the Engineers' Building.

The successful attainment of either of these ends predicates the assistance of a competent chief librarian. The former chief librarian having resigned on August 31, 1910, the administration was placed temporarily in the hands of Miss Alice J. Gates. On December 30, 1910 Dr. W. P. Cutter was appointed librarian of the libraries of the three Founder Societies and United Engineering Society and he assumed office about the first of February, 1911. To accept the appointment, Dr. Cutter, who had previously been connected with the Library of Congress and with the Library of the U. S. Dept. of Agriculture, resigned from the librarianship of the Forbes Library, Northampton, Mass.

The present status of joint occupancy and administration of the library is as follows: There are four separate libraries which are the respective properties of the three Founder Societies and the United Engineering Society. Many parts of the first three have been donated and are subject to limitations prescribed by the deeds of gift. At the suggestion of the United Engineering Society, the Founder Societies (minutes of Board of Directors A. I. E. E., June 12, 1908) agreed " That the administration of the library be placed in the hands of a chief librarian, all employes of the library to be subject to the direction of said chief librarian." As the result of another suggestion from the United Engineering Society, which was approved at the same time, by the Founder Societies, the salaries of all the library employes are now paid by the United Engineering Society and one third of the total amount is charged back to each of the Founder Societies. Any administrative act of the chief librarian, which involves an expenditure by any one of the four societies, must be subject to the constitutional or other limitations prescribed by that society. The Constitution of A. I. E. E. (§50) prescribes that the Library Committee " shall direct expenditures for books or other articles " for the library. The United Engineering Society allows the House Committee, which consists of the secretaries of the three

Digitized by Google

Founder Societies, to direct expenditures which do not exceed $100. To facilitate the work of the chief librarian, therefore, the Library Conference Committee, consisting of one member from each of the Founder Societies, is of service. This committee, representation upon which was authorized by the Institute Board of Directors on October 26, 1906 and March 29, 1907, for diplomatic reasons has assumed merely recommendatory functions and it has been agreed that all its actions must be unanimous. It meets once a month, at the close of the meeting of the House Committee, the members of the latter attending. To this committee the chief librarian makes recommendations, which, if approved, are ultimately referred to the body having power to effectuate the execution. The Institute's representative on this committee must be a member of the Library Committee, and has thus far been its chairman.

Statistical information concerning the library and its use during the year, including a list of donors, is given in the following tables:

DONORS

ACADEMIE ROYALE DES SCIENCES	1
ACHESON, E. G	1
ADAMS, E. D	7
AGENDA DE L'ELECTRO	1
AMERICAN ELECTROCHEMICAL SOCIETY	1
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS	4
ARNOLD, BION J	1
ASSOCIATION OF RAILWAY TELEGRAPH SUPERINTENDENTS	1
BOSTON TRANSIT COMMISSION	1
CALDWELL, EDWARD	1
CHICAGO BUREAU OF STATISTICS	12
COLUMBIA UNIVERSITY, DEPARTMENT OF PHYSICS	2
CONGRESO CIENTIFICO (1° PAN AMERICANO)	2
CROCKER, F. B & ARENDT, M	1
GENERAL ELECTRIC COMPANY	6
HERING, C	1
INDIANA RAILROAD COMMISSIONER	2
INSTITUTION OF OPERATING ENGINEERS	1
INTERNATIONAL ELECTROCHEMICAL COMMISSION	1
INTERNATIONAL ELECTROTECHNIQUE COMMISSION	1
IOWA ENGINEERING SOCIETY	1
ITALY POSTE & TELEGRAFI	2
JANECKE, MAX	1
JOURNAL OF ELECTRICITY, POWER & GAS	1
KARAPETOFF, V	1
MAILLOUX, C. O	8
MARTIN, T. C	4
MASSACHUSETTS GAS AND ELECTRIC LIGHT COMPANY	1
MCCLURG, A. C. COMPANY	1
MCKAY, D	1
MCGRAW PUBLISHING COMPANY	6
MICHIGAN ELECTRIC ASSOCIATION	1
MILLS, JOHN	1

Digitized by Google

NACHOD, C. P.	1	
NATIONAL FIRE PROTECTION ASSOCIATION	1	
NEW JERSEY PUBLIC UTILITY COMMISSIONER	2	
PIERCE, A. L.	1	
POLYTECHNIC INSTITUTE OF BROOKLYN	1	
SEMENZA, G.	1	
SOCIETE INTERNATIONALE DES ELECTRICIENS	1	
TELEFUNKEN WIRELESS TELEGRAPH COMPANY	14	
U. S. ELECTRICAL DEPARTMENT, WASHINGTON	1	
VAN NOSTRAND, D. COMPANY	6	
VERMONT PUBLIC SERVICE COMMISSIONER	1	
VILLARS, G.	3	
WARE, H. E.	1	
WESTERN UNION TELEGRAPH COMPANY	1	
WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY	1	
DONOR UNKNOWN	6	
OLD MATERIAL	79	
		198
Exchanges	199	
Purchases	91	
		290
Total accessions		488

The following tabulation gives the state of the five accounts from which the Library committee is entitled to draw.

DONATIONS (GENERAL LIBRARY FUND)

Dr.		Cr.	
Balance May 1, 1910	$258.04		
Interest May 1, 1911	6.48	Unexpended	$264.52
	$264.52		$264.52

MAILLOUX ENDOWMENT FUND ($1,000)

(Proceeds for the maintenance of certain sets of periodical publications.)

Balance May 1, 1910	$60.35	Expended	$34.00
Interest	15.00	Unexpended	41.35
	$75.35		$75.35

INTERNATIONAL ELECTRICAL CONGRESS OF ST. LOUIS, 1904 FUND.)

(Proceeds available for the purchase of non-American International electrical literature)

Invested in New York City 4½% Bonds			$2268.00
Additions to the fund			49.65
Total fund			$2317.65
Balance on hand May 1, 1910	$129.12		
Interest to May 1, 1911	90.00	Unexpended	$219.12
	$219.12		$219.12

Digitized by Google

WEAVER DONATION

(Available for the purchase of early electrical literature.)

Balance on hand May 1, 1910	$65.44	Unexpended	$65.44
	$65.44		$65.44

INSTITUTE APPROPRIATION ACCOUNT

Dr.		Cr.	
Appropriation for the year ending October 1, 1911	$4,500.00	Librarian and assistants (to January 1, 1911)	$1,005.90
		Cataloguing (to Jan. 1, 1911)	554.00
		Desk attendant (to Jan. 1, 1911)	106.68
		Salary (one-third) of librarian, assistants, cataloguer and desk attendant (Jan. 1 to April 1, 1911)	528.34
		One-third running expenses of library for 1910	106.78
		Books	176.95
		Subscriptions	169.29
		Insurance	72.93
		Binding	322.85
		Miscellaneous	39.58
			$3,083.30
		Unexpended	1,416.70
	$4,500 00		$4,500.00

STATISTICS OF LIBRARY MAY 1, 1911

Source	Volumes	Pamphlets	Valuation
Report of May 1, 1910	14,865	1,279	$25,959.12
Purchases	91		315.84
Gifts and exchanges	288	30	583.50
Old material accessioned	49	34	66.50
	15,293	1,343	$26,924.96

In the following table are given the figures for the total valuation of the Library property:

Books	$26,924.96
Stacks	1,761.05
Furniture, Catalogues, cases, etc	376.00
	$29,062.01

Digitized by Google

LIBRARY ATTENDANCE

	Day	Night	Total
May 1910	454	279	733
June "	471	239	710
July "	609	Closed	609
August "	560	"	560
September "	596	261	857
October "	665	328	993
November "	678	334	1,012
December "	699	306	1,005
January 1911	681	333	1,014
February "	617	334	951
March "	687	334	1,021
April "	756	293	1,049
Total May 1910–April 1911	7,473	3,041	10,514

Mr. Edward D. Adams has continued his contributions to the library as in previous years by the donation of the PROCEEDINGS and TRANSACTIONS of the Royal Society of London, and new volumes of the International Catalogue of Scientific Literature. He has also as heretofore had these volumes bound at his expense.

The income from the C. O. Mailloux Fund of $1000 has again been used to maintain the four important periodical sets which were originally presented to the library by Mr. Mailloux.

Respectfully submitted,

A. BEMENT.
C. F. BURGESS.
GANO DUNN.
J. P. MALLET.
C. E. SCRIBNER.
PHILIP TORCHIO.
SAMUEL SHELDON, *Chairman*.

LIBRARY COMMITTEE.

June 1, 1911

Digitized by Google

Digitized by Google

UNIV. OF MINNESOTA LIBRARY

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 8

August, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Resignation of the Secretary – – – – – – 233
The Chicago Convention – – – – – – 234
Directors' Meeting at Chicago, June 27, 1911 – – – – 240
Associates Elected June 27, 1911 – – – – – 241
Applications for Election—Recommended for Transfer – – – 246
Advanced Study in Electrical Engineering at Massachusetts Institute of Technology – – – – – – – – 246
Past Section Meetings – – – – – – – – 247
Personal – – – – – – – – 249
Obituary—Library Accessions – – – – – – 250

Section II. Papers, Discussions, and Reports

Electrical Engineers and the Public (President's Address). By Dugald C. Jackson, Chicago, June 27, 1911 – – – – – 1727
Problems in Telephone Traffic Engineering. By F. P. Valentine, Chicago, June 28, 1911 – – – – – – – 1735
Electrical Operation of the West Jersey & Seashore Railroad. By B. F. Wood, Chicago, June 28, 1911 – – – – – – 1757
Transmission System of the Central Colorado Power Co. By P. T. Hanscom, Chicago, June 29, 1911 – – – – – 1777
Discussion on "Design, Construction and Tests of an Artificial Transmission Line," "Protection of Electrical Transmission Lines," "Tests of Grounded Phase Protector on the 40,000-Volt System of the Southern Power Co.," "Tests of Losses on High-Tension Lines." Schenectady, February 14, 1911 – – – – – – 1785
Discussion on "Oil Break Circuit Breakers," Schenectady, February 16, 1911 – – – – – – – – 1795
Discussion on "High-Tension Testing of Insulating Materials," "Hysteresis and Eddy Current Exponents for Silicon Steel," "Commercial Problems of Transformer Design," Schenectady, February 14, 1911 1820
Discussion on "Voltage Regulation of Generators," Schenectady, February 16, 1911 – – – – – – – – 1840
Discussion on "The Regulation of Distributing Transformers," "Temperature Gradient in Oil Immersed Transformers," "Dissipation of Heat from Self-Cooled, Oil-Filled Transformer Tanks," "Problems in the Operation of Transformers," Pittsfield, February 15, 1911 – 1842
Discussion on "Mechanical Forces in Magnetic Fields," Pittsfield, February 15, 1911 – – – – – – – 1851
Discussion on "Effect of Temperature on the Hysteresis Loss on Sheet Steel," "Commercial Testing of Sheet Iron for Hysteresis," New York, April 14, 1911 – – – – – – – 1889
Discussion on "Economic Limitations to Aggregation of Power Systems," Boston, Mass., February 17, 1911 – – – – – 1916
Standardization Rules of the A. I. E. E., Adopted June 27,1911 – – 1923

Index to Advertisements – – – – – – iii

Copyright 1911, by the American Institute of Electrical Engineers. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y. December 17, 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

READY

352 Pages 6x9 Inches 139 Illustrations NET $3.00

Electric Central Station Distribution Systems

Their Design and Construction

BY

HARRY BARNES GEAR, A.B., M.E.

Associate, American Institute of Electrical Engineers

AND

PAUL FRANCIS WILLIAMS, E.E.

Associate, American Institute of Electrical Engineers

A THOROUGH, lucid treatment of the general field of distribution from the standpoint of American practice for engineers and students. The treatment is based upon the assumption of a general knowledge of electrical theory such as is possessed by the more advanced students of engineering and by men in practical distribution engineering work. Much of the subject matter of the book is, however, of such a nature as to be easily grasped by practical men who have not had a full theoretical training.

CONTENTS.

CHAPTER I. Systems of Distribution. II. Transmission and Conversion. III. Voltage Regulation. IV. Line Transformers. V. Secondary Distribution. VI. Special Schemes of Transformations. VII. Protective Apparatus. VIII. Overhead Construction: Pole Work. IX. Overhead Construction: Lines and Accessories. X. Underground Construction. XI. Cable Work. XII. Distribution Economics. XIII. Properties of Conductors. XIV. Alternating Current Circuits.

D. VAN NOSTRAND COMPANY

PUBLISHERS AND BOOKSELLERS

23 Murray and 27 Warren Streets - - New York

Digitized by Google

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies.
All other countries $12.00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX August, 1911 No. 8

Resignation of the Secretary

At the meeting of the Board of Directors held at the Hotel Sherman, Chicago June 27, the resignation of Ralph Wainwright Pope, Secretary of the American Institute of Electrical Engineers, was received and accepted by the Board to take effect August 1, 1911. The President was authorized to appoint a committee in coöperation with the President-elect to canvass candidates for the office of Secretary and report its recommendations to the Board of Directors. President Jackson subsequently appointed as this committee, Gano Dunn, Chairman, H. W. Buck and W. S. Rugg.

A committee on resolutions with power was also appointed by President Jackson under authority of the Board which subsequently made the following report.

For more than twenty-six years Mr. Ralph Wainwright Pope has faithfully and loyally served the American Institute of Electrical Engineers as Secretary and for the twenty-seventh consecutive year he has again been elected to the office of Secretary. The Board of Directors and the membership at large are of the opinion that by his continuous and honorable service he has attained such a position in the regard and affections of the members of the Institute that he is entitled to some relief from the active executive duties of his arduous position. Therefore, to carry out his own expressed wishes his resignation as Secretary has been accepted. In accepting his resignation, the Board of Directors, in order to give expression to their own feeling of gratitude as well as the feeling of the membership at large, and in order to reward such long and distinguished service, has appointed him to the position of Honorary Secretary, in which capacity the Institute may still have the benefit of his long experience in its affairs.

In thus complying with the natural and just desire of Mr. Pope the Board of Directors has thought it well to mark this change by this minute expressing its good will and appreciation, and by pointing out that the term of Mr. Pope's service in the Institute covers many of the most important developments in electrical engineering, and that this period has witnessed the growth of the Institute from the humblest beginning to its present flourishing condition.

At the time when the art of electrical engineering was practiced principally in connection with the telegraph, Mr. Pope was a pioneer, having in the year 1858 mastered the working of the Hughes printing telegraph. In 1861 he had charge of the Morse telegraph office at Great Barrington, Mass., in which town he was born in 1844. In 1862 and 1863 he was in the service of the American Telegraph Company in its New York, New Haven and Providence offices, and in 1865 he was one of that band of telegraph pioneers who went into the wilds of British Columbia to establish an overland telegraph system with Europe by means of Alaska and Siberia. In 1867 he was with the Bankers and Brokers Telegraph Company until 1872 when he became an inspector with the Gold and Stock Telegraph Company. While with this company he was promoted to the position of Deputy Superintendent in 1880, at which time the apparatus used by the Gold and Stock Telegraph Company was considered by many as representing the highest development then reached by the electro-mechanical art. While in the service of the Bankers and Brokers Telegraph Company in 1867 he was also assistant Editor of "The Telegrapher". In 1882 he became Manager of the Union Electric Manufacturing Company of New York. In 1884 he was associate editor of "The Electrician and Electrical Engineer". In that same year the American Institute of Electrical Engineers was formed. The next year Mr. Pope was elected its secretary, which position he is about to relinquish. In 1890 he founded the newspaper "Electric Power" and in 1891 he became the editor for electrical terms in the Standard Dictionary. In 1893 under direction of Council, his quarters as Secretary were established in the rooms of the American Institute of Electrical Engineers in the Electrical Building at the Columbian Exposition, and he was appointed on the Committee of Judges for the Department

Digitized by Google

of Electricity. While at the Exposition in Chicago he personally met more than two-thirds of all of the members of the Institute at that time. Ever since Mr. Pope has kept up his large personal acquaintance among the members, which is of great importance to a headquarters official.

During the administration of President Stillwell, Mr. Pope visited a majority of the Sections and many of the Branches of the Institute and made a study of their development and needs. All of these activities have eminently prepared him for the position of Honorary Secretary, giving special attention to the organization and the interest of the sections and branches.

JOHN J. CARTY, *Chairman.*
GEORGE A. HAMILTON.
DAVID B. RUSHMORE.
Committee.

New York, July 28, 1911.

The Chicago Convention

Nineteen years had elapsed since the Institute held a convention in Chicago, and when the location was selected for the twenty eighth convention in 1911, there were early indications of a large attendance.

The total registration was 964, of which 578 were Members or Associates of the Institute, and 386 were guests, including 102 ladies. The local attendance was 548, and the attendance from outside the City of Chicago and suburbs 416.

The following classification by geographical location shows a thoroughly national representation:

Illinois	548
New York	103
Wisconsin	86
Pennsylvania	42
Indiana	26
New England States	25
Ohio	22
Missouri	20
Pacific States	18
South Eastern States	12
Minnesota	13
Michigan	11
Canada	10
New Jersey	8
Iowa	6
Mexico	2
England	1
Scattering	11
Total	964

This is practically double the attendance at any previous convention.

The Hotel Sherman is well adapted for such a convention, the two adjacent halls, and a convenient committee room, with ample room for registration, making the handling of the business details more perfect than is usually possible. Thirty-five papers were presented, which made it necessary to hold two parallel sessions. The local entertainment committee amply provided for recreation between sessions, and lack of time was the only obstacle in the path of well-directed Chicago hospitality.

The first scheduled event was the official reception in the main banquet hall of the Sherman, Monday evening, June 26, at which the local and visiting members were given an opportunity of renewing old friendship, and forming new acquaintances. The receiving line was formed as follows: President Dugald C. Jackson and his sister, Mrs. Louis E. Reber; Past-president Louis A. Ferguson and Mrs. Ferguson; President-elect Gano Dunn and Past-presidents Frank J. Sprague, John W. Lieb, Jr., and Schuyler Skaats Wheeler.

The convention was called to order at 10:20 a.m., Tuesday June 27 by President Jackson who introduced Past-president Ferguson chairman of the Convention Committee at Chicago, who then presented Mayor Harrison's representative MacLay Hoyne, Esq., of the city corporation counsel's office, who welcomed the visiting electrical engineers to Chicago.

President Jackson then delivered his convention address the title of which was "Electrical Engineers and the Public", (printed in full in Section II).

Upon the conclusion of his address, the President introduced Mr. Gano Dunn, President-elect, who expressed his appreciation of the splendid work of the local committee in making such thorough preparation for the business of the convention and for the entertainment of visiting members and their guests. He was deeply sensible of the distinguished honor of being called to the head of an association of the highly professional character of the

Digitized by Google

American Institute of Electrical Engineers, and pledged his utmost efforts to contribute to the continuance of the Institute as the guild, the university, the club of the electrical engineering profession.

The presentation of technical papers then followed, the first being on " The Use of Power-Limiting Reactances, with Large Turbo-Alternators ", by Messrs. R. F. Schuchardt, and E. O. Schweitzer of Chicago, which was read in abstract by Mr. Schuchardt.

The next paper which was abstracted by the author Mr. E. B. Merriam of Schenectady, was entitled, " Tests of Oil Circuit Breakers."

Dr. Charles P. Steinmetz of Schenectady followed with a summary of his paper on the " Development of the Modern Central Station."

The joint discussion of the above papers was taken part in by Messrs. D. B. Rushmore and C. W. Stone of Schenectady, and B. G. Lamme and Charles F. Scott of Pittsburg.

Tuesday afternoon a special train was provided by the Western Electric Company for a visit to the Hawthorne Works. Upon arrival the guests of the company numbering 310, were ready to appreciate an excellent luncheon which was admirably served in the ample dining room, ordinarily used by the employes. The Western Electric orchestra supplied music for the occasion. After luncheon the party was divided into groups, and shown through what is one of the very largest and modern establishments of its kind in the world. The Western Electric Company has 26,000 employees, 14,000 of whom are at the Hawthorne Works. Time did not permit a detailed examination of all the interesting features of this great establishment, but the cable factory in itself was worthy of the careful inspection of the engineers who may have had no previous opportunity to examine this important branch of the electrical industry.

Upon the return trip, the first stop was made at the Fisk Street Station of the Commonwealth Edison Company, which in conjunction with the Quarry Street station near by, have an output of over 204,000 kw. Both of these stations use steam turbine units exclusively. After an inspection of this immense plant, the visitors were conducted to a tent where refreshments had been provided by the company.

The Tuesday evening session was opened with a paper by Mr. H. M. Byllesby of Chicago, on " The Responsibilities of Electrical Engineers in Making Appraisals," and was followed by Mr. Henry Floy, of New York City, on " Depreciation as Related to Electrical Properties." The papers were discussed jointly by Mr. Bion J. Arnold of Chicago, Mr. W. F. Wells of Brooklyn, N. Y., Mr. John W. Lieb, Jr., of New York City, Dr. Schuyler S. Wheeler of Ampere, N. J., Mr. Emil Leonarz of Mexico City, and Professor A. H. Ford of Iowa City, Ia.

The Wednesday morning session was fully occupied with the presentation and discussion of railway papers, the first by Mr. E. F. W. Alexanderson, of Schenectady on " Induction Machines for Heavy Single-phase Motor Service." Mr. B. F. Wood of Altoona followed with a paper entitled " Some Data from the Operation of the Electrified Portion of the West Jersey and Seashore Railroad." The formal presentation of papers at this session was closed by Mr. W. S. Murray of New Haven who resubmitted for further discussion his paper read at an Institute meeting at Toronto, April 7, 1911, entitled, " Electrification Analyzed, and its Practical Application to Trunk-line Roads; Inclusive of Freight and Passenger Operation." The joint discussion of the three papers was opened by Mr. Frank J. Sprague of New York City and continued by Messrs. E. B. Katte of New York City, L. C. Fritch of Chicago, J. L. Woodbridge of Philadelphia, N. W. Storer of Pittsburg, J. W. Lieb, Jr., of New York, C. F. Scott of Pittsburg and President D. C. Jackson of Boston. Written discussions were

Digitized by Google

received from Messrs. Philip Dawson of London and W. N. Smith of New York City. The authors of the papers closed the discussion.

The Electric Club luncheon which followed the Wednesday morning session was one of the most enjoyable features of the convention. As this was planned for the same room, the clearing of the hall, the setting of the tables, and subsequently removing the dishes and furniture, was an object lesson in Chicago " hustling " which was generally appreciated. In extending his greetings to the guests, President H. E. Niesz, outlined the work of the Electric Club, as offering the best possible opportunity for local electrical men to get together, beome better acquainted, and discuss many of the problems which confront them in their business life. President Jackson responded for the Institute, and was followed by President-elect Dunn who called attention to the value to the engineer of personal attendance at conventions.

The session of Wednesday afternoon was devoted to industrial power. The first paper was by Mr. Arthur C. Eastwood of Cleveland, O., entitled " Automatic Motor Control for Direct-current Motors." Mr. E. J. Murphy of Schenectady gave a description accompanied by lantern slides of a device for the same purpose. A paper on " Limitations of Rheostat Control ", by G. R. Radley and L. L. Tatum was then read by Mr. Tatum of Milwaukee, also a paper on " The Control of High-speed Electric Elevators ", by Mr. T. E. Barnum of Milwaukee both being discussed by Messrs. S. N. Clarkson of St. Louis and F. J. Newman of Chicago. The last paper of the session was by Mr. Wilfred Sykes of Pittsburg on " Electrically Driven Reversing Rolling Mills" and was discussed by Messrs. Carl A. Pauly of Schenectady and R. Tschentscher of South Chicago.

Four papers in the field of telegraphy and telephony with their discussion occupied the parallel session Wednesday afternoon, which was presided over by Mr. J. G. Wray of Chicago. The first paper was entitled " Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires." In the absence of the author, Major George O. Squier, the paper was read in abstract by Mr. S. G. McMeen of Chicago, and was discussed by Dr. Frank B. Jewett of New York City, and Messrs. E. F. W. Alexanderson and J. B. Taylor of Schenectady.

A paper by Mr. F. F. Fowle of Chicago on " Telegraph Transmission " was presented by Mr. F. H. Reed of Chicago in the absence of the author, and discussed by Mr. Bancroft Gherardi of New York City and Professor George D. Shepardson of Minneapolis.

The " Commercial Loading of Telephone Circuits in the Bell System " was the title of a paper by Mr. Bancroft Gherardi which was discussed by Messrs. E. H. Bangs of Indianapolis, E. H. Colpitts and E. B. Craft of New York City, Allard Smith and J. G. Wray of Chicago, Dr. F. B. Jewett of New York City, and Professor Shepardson of Minneapolis.

The final paper of the session was by Mr. F. P. Valentine of Boston on "Problems in Telephone Traffic Engineering," and was discussed by Messrs. A. P. Allen and W. Lee Campbell of Chicago, and Mr. Gherardi of New York City.

On Lake Michigan

The steamboat "United States" chartered for a boat ride on the lake, Wednesday evening was boarded at the Clark street bridge by nearly 800 Institute members and guests. The water was smooth, the air clear, and the temperature sufficiently cool for the thorough enjoyment of the trip by all on board. An orchestra furnished music for dancing, and refreshments were available at all times. This trip afforded a splendid opportunity to see the extensive electric lighting of Chicago as it appears from a distance.

High-tension transmission problems occupied the Thursday morning session, Mr. Percy H. Thomas, presiding.

Digitized by Google

The first paper was by Mr. G. Faccioli of Pittsfield on "Electric Line Oscillations" and was presented in abstract by Dr. Steinmetz. The discussion was by Messrs. M. H. Collbohm of Madison, Wis., D. B. Rushmore of Schenectady, and Percy H. Thomas of New York City.

"The Dielectric Strength of Air" was the title of the next paper, and was presented in abstract by the author, Dr. J. B. Whitehead of Baltimore. "The Law of Corona and the Dielectric Strength of Air" was the subject of a paper by Mr. F. W. Peek of Schenectady which followed that of Dr. Whitehead, and was jointly discussed with it by Dr. Steinmetz and Mr. C. M. Davis of Schenectady, Mr. A. B. Hendricks of Pittsfield, and Mr. Chas. F. Scott of Pittsburg.

Information regarding transmission systems elicited by inquiries made by his committee were summarized by Chairman Thomas in reports to J. P. Jollyman for the Great Western Power Company, W. S. Lee for the Southern Power Company, and P. T. Hanscom for the Central Colorado Power Company. A discussion followed by Messrs. Collbohm of Madison, L. C. Nicholson of Buffalo, Paul M. Lincoln of Pittsburg, and N. J. Neall of Boston.

The Gary Steel Works

Thursday afternoon was occupied with a trip to the Gary (Ind.) Steel Works. A special train by the Lake Shore railroad was furnished through the courtesy of the General Electric Company, and left Chicago at 2 p.m. Arriving at the works, the entire party was transferred to a train of special sight-seeing cars, which ran over the system of tracks in the yards, enabling the visitors to comprehend the magnitude of this great establishment. The new coke oven plant, the ore unloading docks, the unloaders and ore bridges were visited in turn. The bridges and unloaders were seen in operation. Then followed the blast furnaces, the blowing engine house, the open hearth plant, the rail, billet and merchant mills. There being over 400 people on board it was found inexpedient to attempt an inspection of the interior of the buildings, but some of the members who were especially interested in the application of electricity to rolling mill work availed themselves of an invitation to examine the plant before leaving the city. Upon the return trip the train reached Chicago at 6:30 p.m.

Section Delegates in Conference

One of the interesting features of recent annual conventions has been the conference of the Institute officers and Section delegates. Chairman Paul M. Lincoln recognized the importance of the delegates preparing themselves to discuss various topics of interest to the Sections and opened up correspondence with the various chairmen several months in advance of the convention.

The conference was called to order by Chairman Lincoln, Thursday evening, who invited the views of delgates as to coöperating with local engineering societies.

Professor George A. Hoadley of Philadelphia, believed there should be concentration of effort, in the relations of sections with local societies, and referred to the plan which had brought good results in St. Louis.

Professor A. S. Langsdorf of St. Louis said that a joint committee from the different local organizations made a plan of coöperation under the lead of the Engineers Club. A joint council has charge of meetings and programs and the result has been satisfactory. Mr. L. L. Tatum of Milwaukee said that all section members in that city, were accepted as members of the Milwaukee Engineers' Society, upon payment of dues at a reduced rate. They were entitled to all the privileges of the society which included attendance at all meetings and the joint use of the rooms.

Mr. N. J. Neall of Boston explained the practice in that city by which

Digitized by Google

delegates from four engineering societies serve on a joint board. They arranged for three joint meetings during the season, one under the auspices of each society, and also an engineering dinner, attendance at which has been as high as 400. He also referred to the advantages and economy of a joint mailing list in carrying on the work. Secretary Pope emphasized the importance of coöperating with local societies wherever they existed, as in this way engineers could exert greater influence upon local engineering questions in which every citizen was interested. He believed that sections should be organized even if meetings were not held regularly, as in this way members could be called together if necessary at any time.

Mr. E. Leonarz of Mexico City, spoke of the difficulties of obtaining a suitable meeting place, and for this purpose alone there should be coöperation. President D. C. Jackson addressed the conference upon general Institute affairs, pointing out the national character of the organization, and the close attention given by the Board of Directors to its affairs. In announcing the resignation of the Secretary, the President stated that Mr. Pope has completed the twenty-sixth consecutive year in that office, and that in recognition of his notable services, the Board of Directors had voted to continue his connection with the Institute as Honorary Secretary at his present salary giving his attention to the welfare of the Sections.

Delegates Tribute to the Secretary

The Section Delegates of the American Institute of Electrical Engineers, present at the Twenty-Eighth Annual Convention, having learned of the resignation of Mr. Ralph W. Pope, from the office of Secretary, and his appointment as Honorary Secretary, unanimously desire to place on record their grateful appreciation of the interest which he has shown in the welfare of the Sections, and of his unfailing courtesy in dealings between the office at headquarters and the Section officers. They wish, further, to give expression to the high personal regard and esteem in which he is held by all of them, and to their satisfaction in the knowledge that the past friendly relations will be continued in the discharge of the duties of the new position to which he has been appointed.

E. Arthur Baldwin, Schenectady Section.
J. G. Wray, Chicago Section.
George S. Macomber, Ithaca Section.
S. G. McMeen, San Francisco Section.
Geo. A. Hoadley, Philadelphia Section.
N. J. Neall, Boston Section.
E. Leonarz, Mexico Section.
J. B. Whitehead, Baltimore Section.
E. P. Whitney, Seattle Section.
E. A. Wagner, Ft. Wayne Section.
Geo. J. Yundt, Atlanta Section.
H. A. Kirkland, Portland Section.
A. S. Langsdorf, St. Louis Section.
J. N. Cadby, Madison Section.
E. R. Northmore, Los Angeles Section.
S. H. Blake, Pittsfield Section.
J. M. Bryant, Urbana Section.

Secretary Pope in response referred to the pleasant relations that had existed between him and the members, and the interest he had felt in the growing importance of the Sections. He had realized that the time must come when he would necessarily be obliged to relinquish the responsibilities of the Secretary's office, and that the arrangements now made would be for the best interests of the Institute.

Mr. Gano Dunn President-elect addressed the conference upon the question of Institute nominations and elections; and the possibility of improving the methods heretofore in use and thus avoiding the criticism which had been aroused. In closing Mr. Dunn announced the reappointment of Mr. Paul M. Lincoln as Chairman of the Sections Committee which elicited hearty applause.

The following resolutions, submitted by committees of the Section delegates were carried unanimously:

Resolved, that it is the sense of this meeting that the Constitutional amendment relative to the manner of selecting the Secretary should be resubmitted to the membership for its decision; and that, further, it is recommended that such amendment be submitted in the clearest possible form.

Resolved, That this meeting recommends that on account of the long and faithful service of Mr. Ralph Wainwright Pope as Secretary of the American Institute of Electrical Engineers, he be appointed Honorary Secretary for life, at the salary he is now receiving.

Digitized by Google

The general session Friday morning was presided over by Professor George F. Sever of New York City, Chairman of the Meetings and Papers Committee.

The first paper was entitled "Economical Design of Direct-current Electromagnets." Professor C. E. Magnusson of Seattle and Mr. G. H. Smith were the authors of the next paper on "Electrolytic Corrosion in Reinforced Concrete", which Professor Magnusson presented in abstract. It was discussed by Messrs. Burton McCollum of Washington, D. C., E. W. Stevenson of Wilkes Barre, and Professors Geo. A. Hoadley of Swarthmore Pa., A. S. Langsdorf of St. Louis, and Geo. D. Shepardson of Minneapolis. Discussions by letter were received from Messrs. Guy F. Shaffer, Maximilian Toch and Harry Barker of New York. A paper on "Wave Shape of Currents in an Individual Rotor Conductor of a Single-phase Induction Motor," by Mr. H. Weichsel of St. Louis was abstracted by the author and discussed by Mr. Theodore Hoock of Wilkinsburg, Pa.

A paper on "The Choice of Rotor Diameter and Performance of Polyphase Induction Motors" was presented by the author, Mr. Theodore Hoock, and was discussed by Messrs. E. F. W. Alexanderson of Schenectady, C. J. Fechheimer of Ampere, N. J., and H. Weichsel of St. Louis.

Papers followed by Mr. J. R. Craighead of Schenectady on "The Application of Current Transformers in Three-phase Circuits;" by Messrs. R. W. Atkinson and E. C. Stone of Pittsburg, on "The Cost of Transformer Losses." These papers were discussed together by Messrs. A. H. Pikler of Ampere, N. J., W. C. Smith of Pittsfield, Mass., E. A. Wagner of Fort Wayne and H. B. Gear of Chicago.

The parallel session Friday morning was devoted to high-tension transmission, and was presided over by Mr. D. B. Rushmore of Schenectady. The following papers were presented and discussed jointly: "The Solution to Problems in Sags and Spans," by W. L. R. Robertson of Philadelphia; "The Mechanical and Electrical Characteristics of Transmission Lines," by Dr. Harold Pender and Mr. H. F. Thomson (read by Mr. Thomson) and "Sag Calculations for Suspended Wires," by Mr. Percy H. Thomas. These three papers were discussed together by Messrs. D. B. Rushmore of Schenectady, Paul M. Lincoln of Pittsburg, L. C. Nicholson of Buffalo, N. J. Neall of Boston, J. B. Balcomb and W. E. Belcher of Chicago and Percy H. Thomas of New York.

The final paper of the session was presented by Mr. A. O. Austin of Barberton, O., on "The High-Efficiency Suspension Insulator" and was discussed by Messrs. E. E. F. Creighton of Schenectady, Paul M. Lincoln of Pittsburg, L. I. Thomas of Chicago and N. J. Neall of Boston. At both the regular and parallel sessions the following resolutions as reported by a committee appointed by the President, were read and adopted:

Resolved, that the members of the American Institute of Electrical Engineers, in attendance at the Annual Convention in Chicago, desire to express their grateful appreciation and tender their heartfelt thanks to Mr. L. A. Ferguson and members of the Convention Committee, to Mr. H. M. Byllesby and members of the Entertainment Committee, to the ladies of Chicago, the Chicago Electric Club, and to the commercial organizations, for the courtesies extended and for the entertainment so generously and lavishly provided.

The extraordinary success of the Chicago Convention, the greatest in the annals of the Institute, redounds to the credit of those responsible for its arrangements and attests the suitability of the great metropolis as a convention city.

And be it further resolved, that a copy of these resolutions be published in the Institute PROCEEDINGS.

C. E. MAGNUSSON
A. S. LANGSDORF
DAVID B. RUSHMORE, *Chairman.*
} *Committee.*

At the closing session, Friday afternoon, Professor A. S. Langsdorf, Chairman of the Educational Committee presided. A paper was presented by Mr. Ralph D. Mershon of New York City, the subject of which was "Tenta-

Digitized by Google

tive Scheme of Organization and Administration of a State University." The paper was read by Professor John H. Hunt of Columbus, O., in the absence of the author. The discussion was opened by Professor A. H. Ford of Iowa City and continued by Professor C. F. Harding of Lafayette, Ind., Professor B. B. Brackett of Brookings, S. D., Professor A. S. Langsdorf of St. Louis, Professor Geo. D. Shepardson of Minneapolis and Professor M. C. Beebe of Madison, Wis.

Additional written discussion on the papers read at the convention have been received from the following:

J. D. Nies, S. Haar, W. C. Smith, A. B. Hendricks, Jr., J. F. Vaughan, W. L. Upson, P. Junkersfeld, Horatio A. Foster, R. E. Hellmund, R. B. Williamson, Charles P. Steinmetz, John B. Taylor, J. G. Hirsch, Edwin B. Katte, E. F. Alexanderson, P. H. Thomas, Geo. L. Hoxie, W. A. Delman, F. G. Gasche, R. Tschentscher, Theodore Hoock, Clarence P. Fowler, Béla Gáti, John J. Frank, M. H. Collbohm, W. L. Waters, R. C. Darrow, and J. L. Woodbridge.

The Secretary announced that President Jackson had been obliged to leave the city in order to reach a steamer for Europe on Saturday whereupon Vice-President Lincoln assumed the chair and declared the twenty-eighth convention adjourned.

Social Features

While the reception and dance on Monday evening was an official function, it was followed during the week by several social gatherings; the facilities of a large city being especially favorable for the organization of parties of congenial friends. In this respect the Chicago convention was preëminent in the history of the Institute.

There were 102 ladies registered and the local committee made adequate arrangements for their entertainment. Wednesday afternoon, there was a ladies' reception and tea at the Art Institute galleries and on Thursday afternoon an automobile tour through the park system, with an elaborate luncheon in the orangerie of the South Shore Country Club, at which 62 ladies were present. At the same time President Jackson, President-elect Dunn, and Past-presidents Martin, Sprague, Crocker, Steinmetz, Arnold, Wheeler and Lieb were the guests of Past-president Ferguson at a luncheon in the Dutch grill room of the Club. Music was furnished by Tomaso's orchestra, and instrumental and vocal selections were rendered by a band of Venetian musicians in costume, which were highly appreciated by the ladies.

Monday evening Mr. and Mrs. Ferguson gave a private dinner to President Jackson and his sister Mrs. Reber, President-elect Dunn and Mr. and Mrs. Sunny.

Thursday evening Mr. H. M. Byllesby gave an elaborate dinner at the Chicago Club, the guests of honor being the President of the Institute and the President-elect. About 60 guests were present. The speakers were Messrs. Byllesby, Jackson, Dunn, Insull, Dawes and Reynolds.

An informal dinner organized by the members of the Chicago Tau Beta Pi took place at 6 o'clock Wednesday evening in the Rose room at the Hotel Sherman, about 40 being present. The arrangements were made by Mr. Ralph H. Rice, Chairman of the Chicago Tau Beta Pi Alumni Association, who introduced Past-president Arnold as toastmaster. Brief speeches were made by Messrs. Jackson, Dunn, Abbott and Professor Shepardson.

Directors' Meeting at Chicago, June 27, 1911

A meeting of the Institute Board of Directors was held at the Hotel Sherman, Chicago, on June 27, 1911. The directors present were: President D. C. Jackson, Boston, Mass.; Vice-President P. M. Lincoln, Pittsburg, Pa.; Managers David B. Rushmore, Schenectady, N.Y. Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis.,

Digitized by Google

S. D. Sprong, New York, W. S. Rugg, New York, C. E. Scribner, New York, and Secretary Ralph W. Pope, New York.

One hundred and forty-seven applicants for membership in the Institute as Associates were elected. The names of the Associates elected are printed elsewhere in this issue.

The following Associates were transferred to the grade of Member: Charles W. Parkhurst, Walter H. McCoy, G. Faccioli, Robert Howes.

Associates Elected June 27, 1911

ALMERT, HAROLD, Manager, Dept. of Examinations, and Reports, H. M. Byllesby & Co., 206 So. La Salle St., Chicago, Ill.

AMES, MILLARD EVERETT, Manager, A. S. Schulman, 904 Plymouth Bldg.; res., 4652 Lake Ave., Chicago, Ill.

ARMBRUST, GEORGE MAURICE, Engineering Dept., Commonwealth Edison Co., 28 N. Market St.; res., 668 Sheridan Road, Chicago, Ill.

BAIRD, LOUIS SAMUEL, Engineer, Adams-Bagnall Electric Co., 600 Huron Road, Cleveland, Ohio.

BALL, JOHN DUDLEY, Laboratory Assistant, General Electric Co.; res., 38 Furman St., Schenectady, N. Y.

BALZARI, ROBERT ALMON, Salesman, Westinghouse Electric & Mfg. Co., 165 2nd St., San Francisco, Cal.

BARNES, SAMUEL WALKER, Sales Engineer, Westinghouse Electric & Mfg. Co., 406 New England Bldg., Kansas City, Mo.

BARRY, JAMES MILNE, Assistant, Underground Electrical Distribution Dept., Pacific Gas & Elec. Co., Sacramento, Cal.

BEATY, WALTER EDWARD, Electrical Engineer, Union Gas & Electric Co.; res., 639 West 7th St., Cincinnati, O.

BENTLEY, HARRY H., Electrical Engineer, Westinghouse Electric & Mfg. Co., 526 West 25th St., New York City.

BIRD, PAUL P., Contract Dept., Commonwealth Edison Co., 120 W. Adams St.; res., 1365 East 48th St., Chicago, Ill.

BIRD, ROBERT C., Inspector Fire Underwriters' Electrical Bureau, 68 William St., New York City; res., Woodhaven, N. Y.

BOWDLE, JOHN WESLEY, Superintendent of Equipment, San Diego Home Tel. Co., San Diego, Cal.

BRANN, FRANK J., Construction Foreman, Ford, Bacon and Davis; res., 3724 Army St., San Francisco, Cal.

BRILLHART, HOWARD EDWIN, Station-foreman, Great Falls Power Co., Anaconda, Mont.

BULL, AMASA COBB, Electrical Engineer, H. M. Byllesby & Co., 206 La Salle St.; res., 6248 Jackson Park Ave. Chicago, Ill.

BURROWS, WILLIAM HERBERT RUDOLPH Electrical and Mechanical Engineer, Nipissing Mining Co., Ltd., Cobalt, Ont.

CALHOUN, JAMES R., Sears, Roebuck & Co., Homan & Harvard Sts., Chicago, res., Elmhurst, Ill.

CAMPBELL, CREIGHTON CHILD, Salesman, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.; res., Bluefield, W. Va.

CASE, HERBERT MONROE, Commercial Engineer, General Electric Co., 30 Church St., New York City.

CHAMBERLIN, HERBERT BARSTOW, Salesman, Crocker-Wheeler Co., Chicago; res., 1711 East 55th St., Hyde Park, Ill.

CHANDLER, MAX, Testing Department, North Shore Electric Co., 139 La Salle St., Chicago; res., 420 Western Ave., Blue Island, Ill.

CLIFFORD, E. PRESTON, Manager, Western Electric Co., 463 West St.; res., 309 West 83rd St., New York City.

COHN, MATHIAS ALVIN, Student, Cornell University, Ithaca, N. Y.

COLE, TOM RANDOLPH, Student, University of Texas; res., 310 West 26th St., Sherman, Tex.

Digitized by Google

COLPITTS, EDWIN HENRY, Research Engineer, Western Electric Co., 463 West St., New York City.

CONNALLY, WILLIAM BENJAMIN, Isthmian Canal Commission, Balboa, Canal Zone.

COOKE, ALBERT F., Electrical Engineer, Mt. Hood Railway & Power Co., 604 Lewis Bldg., Portland, Ore.

CRAFT, EDWARD BEECH, Development Engineer, Western Electric Co., 463 West St., New York City.

CROSBY, GEORGE LOCKE, District Manager, Machado & Roller, 1536 Oliver Bldg., Pittsburg; res., 855 Rebecca St., Wilkinsburg, Pa.

CURPHEY, JOHN ALFRED, Chief Operator, Shawinigan Water & Power Co., Power Bldgs., Craig St., Montreal, Canada.

DAVENPORT, FRANK BEALL, Adjunct Professor of Electrical Engineering, Georgia School of Technology; res., 245 East Pine St., Atlanta, Ga.

DAVIS, CLYDE LINDSLY, Electrical Engineer, Tonopah Mining Co., Tonopah, Nev.

DENMAN, BURT J., Engineer, Edison Electric Illuminating Co.; res., 123 Collingwood Ave., Detroit, Mich.

DEWEY, HERBERT HOPKINS, Power & Mining Engineering Dept., General Electric Co.; res., 37 Haigh Ave., Schenectady, N. Y.

DIETZ, CHARLES LUDWIG, Superintendent and Chief Electrician, Commonwealth Power Co.; res., 905 19th St., Milwaukee, Wis.

DOVER, ELMER, Assistant Secretary and Treasurer, H. M. Byllesby & Co., 206 South La Salle St., Chicago, Ill.

DRUM, ALPHONSE L., Consulting Engineer, A. L. Drum & Co., American Trust Bldg., Chicago, Ill.

DUNLOP, ARTHUR, Salesman, National Electrical Supply Co ; res., 1701 Park Road, Washington D. C.

DU PRIEST, JOHN RANDALL, Chief Engineer, Columbus Machine Co.; res., 1461 Worthington St., Columbus, O.

EDWARDS, JOHN DEARLING, Superintendent Electrical Construction, Terminal Power Co., Venice, Ill.

EWING, DRESSEL DE WITT, Professor of Electrical and Mechanical Engineering, Ohio Northern University, Ada, Ohio.

FINNICUM, JOHN LYLE, Salesman, Doubleday Hill Electric Co., 919 Liberty St., Pittsburg, Pa.

FLEAGER, CLARENCE EARL, Division Plant Engineer, Pacific Telephone & Telegraph Co., 86 West Mission St., San Francisco, Cal.

FORD, BRUCE, Electric Storage Battery Co., Allegheny Ave. & 19th St.; res., 25 E. Summit St., Chestnut Hill, Philadelphia, Pa.

FORT, WILLIAM LAPHAM, Buyer, Western Electric Co., 463 West St.; res., 226 West 59th St., New York City.

FREEMAN, WALTER CLARKSON, Salesman, Stromberg-Carlson Tel. Mfg. Co.; res., 49 Darwin St., Rochester, N. Y.

GILCHRIST, THOMAS ERNEST, Testing Department, Canadian General Electric Co.; res., 179 Aylmer St., Peterboro, Ont.

GLEASON, ROBERT RIPLEY, Assistant Traffic Chief, American Telephone & Telegraph Co., Chicago, Ill.

GRANT, HARRY LAMAR, Sales Manager, Western Electric Co., 500 S. Clinton St., Chicago, Ill.

GREENLAND, SAMUEL WILSON, Ft. Wayne and Wabash Valley Traction Co., Ft. Wayne, Ind.

HAGERMAN, JOHN DE WITT, Construction Foreman, Hydro Electric Power Commission, Continental Life Bldg., Toronto, Ont.

HARPER, FREDERICK, Electrical Engineer, Automatic Transportation Co., 2933 Main St.; res., 15 Custer St., Buffalo, N. Y.

HARVEY, SPENCER G., Cadet Engineer, Public Service Railway Co., Newark; res., 463 Main St., Orange, N. J.

HECKER, GUY CLIFFORD, Electrical Department, Pittsburg Railways Co., 435 6th Ave.; res., 352 Melwood St., Pittsburg, Pa.

Digitized by Google

HEDBERG, FRITZ ARTHUR, Erecting Engineer, Westinghouse Electric & Mfg. Co., 768 Ellicott Sq., Buffalo, N. Y.

HEMPHILL, ROBERT WILLIAM, JR., Division Manager, Eastern Michigan Edison Co., 200 East Washington St., Ann Arbor, Mich.

HINE, STANLEY DYER, MichoacanPower Co., Villasenor, Guanajuato, Mex.

HOLMES, ROBERT, Electrical Engineer, T. Pringle & Son, 419 Coristine Bldg., Montreal, Que.

HOPKINS, ERNEST MARTIN, Manager Educational Dept., Western Electric Co., Hawthorne; res., La Grange, Ill.

HUHN, CHARLES GUENTHER, Superintendent, Williamstown Junction, N. J.

IREMONGER, ARTHUR CHARLES, Chief Operator, Shawinigan Water & Power Co., Shawinigan Falls. Quebec.

JACKSON, EBERT ANDREW, Electrical Engineer, Golden Cycle Mining Co.; res., 1128 Colorado Ave., Colorado Springs, Colo.

JACOBSEN, ARNT, Electrical Machinist, Seattle-Tacoma Power Co.; res., 1017 Jefferson St., Seattle, Wash.

JAMES, HERNY CLAY, JR., Student, St. Paul Gas Light Co.; res., 1043 Laurel Ave., St. Paul, Minn.

JAQUA, CHARLES AVERY, Assistant Sales Manager, Waverley Company; res., 2429 Ashland Ave., Indianapolis, Ind.

JEFFREY, FRASER, Electrical Engineer, Allis-Chalmers Co., West Allis; res., 20 St. James Court, Milwaukee, Wis.

JONASON, BROR ALGOT, Assistant Electrical Engineer, Holtzer Cabot Electric Co., 621 Albany St., Boston, Mass

JONES, BRUCE BLACKBURN, Electrical Draftsman Hydro-Electric Power Commission of Ontario, Toronto,Ont.

KELLOGG, EDWARD WASHBURN, Instructor in Electrical Engineering, Missouri University; res., 511 Turner Ave., Columbia, Mo.

KETCHAM, FRANK A., Assistant Manager, Western Electric Co., Chicago, Ill.

KNAPP, LELAND GARFIELD, Designing Engineer, Marion Steam Shovel Co.; res., 259 West Church St., Marion, O.

KENNEDY, SAMUEL MACAW, General Agent, Southern California Edison Co., Los Angeles, Cal.

KRUMBIEGEL, KURT, Director of Electric Power Plants, Actiengesellschaft Lauchhammer, Lauchhammer, Ger.

LEE, CORLISS E., Electrical Engineer, General Electric Co.; res., 60 Stratford Ave., Pittsfield, Mass.

LEWIS, DONALD MACNAUGHTON, Assistant to Engineer, Livingston-Niagara Power Co., Avon; res., 503 Colver Rd., Rochester, N. Y.

LINTON, THOMAS, Chief Operator, Huronian Power Co., Turbine, Ont.

LIX-KLETT, ERNESTO, Electrical Engineer, E. Lix-Klett & Co., Libertda 1088, Buenos Aires, A. R.

LONG, CECIL, Assistant Electrical Engineer, Winnipeg Electric Railway Co., Winnipeg, Man.

LOW, FRANK YATES, Electrical Engineer H. M. Byllesby & Co., 206 La Salle St.; res., 1375 East 54th Street, Chicago, Ill.

LYNN, SCOTT, Electrical Engineer, Sangamo Electric Co.; res., 509 E. No. Grand Ave., Springfield, Ill.

LYTLE, BRUCE HAMILTON, Engineer, Westinghouse Electric & Mfg. Co.; res., 1105 Portland St., Pittsburg, Pa.

MACDIARMID, ARCHIBALD ALEXANDER, Montreal Light, Heat & Power Co.; res., 206 Milton St., Montreal, Que.

MALM, THURE, Electrical Engineer, Stone & Webster Engineering Corp'n. Minneapolis, Minn.

MANCIB, ALVINE STEWART, Electrical Engineer, Barnes & Loud Electric Co., 57 Weybosset St., Providence, R. I.

MARCY, FRANK EARL, District Manager, Allis-Chalmers Co.; res., 74 P Street, Salt Lake City, Utah.

MARSHALL, JOHN JAMES, Assistant Superintendent of Machinery, United States Mint, San Francisco, Cal.

MATHEWS, HAMMOND, Chief Electrician Arizona Copper Co., Clifton, Arizona.

Digitized by Google

McCARTHY, GEORGE ARNOLD, Manager Calgary Branch, Smith, Kerry & Chace, Room 3, Bank B. N. A. Bldg., Calgary, Alberta.

McINTOSH, LOUIS CLIFFORD, Assistant Manager, Southern Pacific General Telegraph, 488 Pacific Electric Bldg., Los Angeles, Cal.

McLEAN, GEORGE LEROY, Sales Engineer, Westinghouse Electric & Mfg. Co., East Pittsburg, Pa.

McLEAN, THOMAS, Meter Tester, Los Angeles Gas & Electric Corp'n., 645 South Hill St., Los Angeles, Cal.

MEANS, CHARLES M., Electrical Engineer, Rochester & Pittsburg Coal & Iron Co.; res., 420 East Mahoning St., Punxsutawney, Pa.

MENZEL, ALBERT FRANKLIN, Construction Foreman, General Electric Co., Nevada Bank Building, San Francisco Cal.

MIZUNO, SEIICHI, Engineer, Mitsui & Co., Ltd., 445 Broome St.; res., 606 West 113th Street, New York City.

MOULD, EDMUND FREEMAN, Engineer, Adams Bagnall Electric Co., 7218 Stanton Ave., Cleveland, Ohio.

MURRAY, J. FRANK, Superintendent Meters and Standardizing Dept., United Electric Light Co., Springfield, Mass.

NIEMANN, EDWARD, Junior Railway Engineer, Public Service Commission, 1st Dist., 154 Nassau St., New York City.

NIMS, DAVID E., Industrial Engineer, Kansas City Electric Light Co.; res., 1008 Paseo St., Kansas City, Mo.

NORMAN, CHARLEY MAURICE, Foreman, Electric Repair Dept., General Electric Co., 365 East Illinois St., Chicago, Ill.

OKAMOTO, TAKASUKE, Chief Engineer, Nagoya Electric Light Co., Nagoya, Japan.

O'MEARA, WILLIAM JOHN, General Foreman, N. Y., N. H. & H. R.R. Co., Grand Central Terminal; res., 112 West 48th St., New York City.

PIERCE, DANA, ELECTRICAL Engineer, Underwriters' Laboratories, Inc., 207 East Ohio St., Chicago, Ill.

PINDELL, DAVID STERRETT, Electrical Engineer, American Agricultural Chemical Co., Room 76, 92 State St., Boston, Mass.

PINGREY, FRANK MILTON, Commercial Electrical Engineer, Machado & Roller, 1536 Oliver Building, Pittsburg, Pa.

PIZZINI, JAMES A., Sales Manager, Western Electric Co., 463 West St.; res., 930 West End Ave., New York City.

PLAYER, GEORGE POLK, Telephone Engineer, Corporation Commission of Oklahoma, Oklahoma City, Okla.

QUASS, RALPH LEROY, Telephone Enginner, Western Electric Co., 463 West St.; res., 40 West 12th St., New York City.

QUINN, T. G., Superintendent, Alaska Water Light & Tel. Co., Valdez, Alaska.

RAWSON, FREDERICK P., Electrical Engineer, Mt. Hood Railway & Power Co., 608 Lewis Bldg., Portland, Ore.

RESCH, KNUTE J., Erecting Engineer, Westinghouse Electric & Mfg. Co., 1428 New York Life Bldg., Chicago, Ill.

RICHARDS, HOWARD, JR., Electrical Engineer, 119 East 71st Street, New York City.

RICHARDSON, ALBERT HEWES, Sales Agent, General Electric Co., Provident Bank Bldg., Cincinnati, Ohio.

ROCKWELL, HORACE LEWIS, Patent Attorney, 1609 Fort Dearborn Bldg.; res., 1240 Dearborn Ave., Chicago, Ill.

ROTH, CHARLES H., President, Roth Bros. & Co., Adams & Loomis Sts.; res., 2344 So. Lawndale Ave., Chicago, Ill.

ROULE, FRANCIS, Superintendent, Horicon Light & Power Co., Horicon, Wis.

SCHAEFFER, GEORGE HENRY, Chief Electrician, Carpenter Steel Co., Reading, Pa.

SCHRAMM, ADOLF PAUL CONSTANTIN Electrical Engineer, with Charles Engelhard, 30 Church St., New York City.

Digitized by Google

SCOTT, SEATON MACKENZIE, Sales Engineer, Evans, Almirall & Co., Dominick & Clarke Sts., New York City.

SHAVER, GEORGE WALTER, Engineer, Westinghouse Electric & Mfg. Co., 165 Second St.; res., 1032 33rd Ave., Oakland, Cal.

SHEPPARD, CREEDY COLLINS, 1st Lieutenant, Ordnance Dept., United States Army, Sandy Hook Proving Ground, Fort Hancock, N. J.

SHOTWELL, RALPH ERNEST, Meter Testing and Repairing, Edison Electric Light Co., 27 West Market St., York, Pa.

SMETHURST, WILLIAM, Chief Electrical Engineer, John Musgrave & Sons, Ltd., Kay St., Bolton, Lancashire, England.

SMITH, BURKE, Engineering Department, Chicago Telephone Co.; res., 5656 Monroe Ave., Chicago, Ill.

SMITH, HOMER KEPHART, Electrical Superintendent, Pacific Division, Isthmian Canal Commission, Corozal Canal Zone.

SMITH, JONATHAN ALOYSIUS, Installation Foreman, Western Electric Co., Hawthorne, Ill.

SOMERS, RICHARD HERBERT, Captain, Ordnance Dept., United States Army Sandy Hook Proving Ground, Ft. Hancock, N. J.

SPENCE, THOMAS EDWARD, Power Engineer, Luzerne County Gas & Electric Co., Kingston, Pa.

STAATS, EDWARD POMEROY, Engineering Assistant, N. Y. Telephone Co., 15 Dey St., res., 661 West 179th St., New York City.

STEWART, CLAUDIUS FLETCHER, Installer, Automatic Electric Co., Chicago, Ill.

STEWART, GEORGE SHIPLEY, Agent, Canadian General Electric Co.; res., 90 Borden St., Toronto, Ont.

SUTTON, LOUIS VALVELLE, General Electric Co., Lynn, Mass.

TALLMAN, PAUL BERTRAM, Supervising Architect & Engineer, Warren & Wetmore, 3 East 33rd St.. New York City.

TAYLOR, SYDNEY WENTWORTH, JR., Secretary and Treasurer, Staunton Dielectrile Rubber Co., Muskegon, Mich.

THOMPSON, WILLIAM J., Thompson-Livering Co., 244 Arch St.; res., 5134 Spruce St., Philadelphia, Pa.

TURNER, CHARLES ALEXANDER, Electrical Engineer, Pacific Telephone & Telegraph Co., 140 New Montgomery St., San Francisco, Cal.

UIHLEIN, OSCAR LOUIS, Electrical Engineer, Cutler-Hammer Mfg. Co., res., 601 Galena St., Milwaukee, Wis.

VANDERVOORT, GERALD, Electric Power Co., Ltd., Belleville, Ont.

VAN SISE, FORREST WHITNEY, Electrician, Queens Borough Gas & Electric Co., Far Rockaway, N. Y.

VEUVE, ERLE LEROY, Consulting Engineer, 693 Pacific Electric Bldg.; res., 177 Ardmore Ave., Los Angeles, Cal.

WALKER, CRANFORD PERRY, Instructor in Testing, Bliss Electrical School, Takoma Park, Washington, D. C.

WALLACE, CARL JOSEPH, Manager Electrical Dept., Sprague-Waldo Mfg. Co., 19–23 Harper Ave., Detroit, Mich.

WHITECOTTON, OTTO G., Assistant Superintendent of Construction, Schenectady Illuminating Co.; res., 336 Summit Ave., Schenectady, N. Y.

WINDER, CLARENCE A., General Electric Co., 681 Ellicott Sq., Buffalo, N. Y.

WOOD, CECIL, Electrical Draftsman, Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

WOOD, CHARLES PARKINSON, Secretary and Manager, Producer Sales Dept., Gibbs Gas Engine Co., Walton Bldg., Atlanta, Ga.

WRIGHT, ORVILLE C., Electrical Engineer, Motive Power Dept., Pennsylvania Lines, Fort Wayne, Ind.

Digitized by Google

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before August 25, 1911.

10582 Cochran, C. E., Cleveland, O.
10583 Sainz, J. M., Boredeaux, France.
10584 Frost, W. B., St. Louis, Mo.
10585 Saeger, R. A., Ankona, Fla.
10586 Blackley, S., Wellington, N. Z.
10587 Douglas, H. B., Hammond, Ind.
10588 Evers, A. E., Oakland, Cal.
10589 Farwell, S. P., Champaign, Ill.
10590 Henderson, H. W. W., Bengal, India.
10591 Holland, H. N., Mysore, India.
10592 Lustig, L., Schenectady, N. Y.
10593 Milton, T., Chicago, Ill.
10594 Ogur, E., Astoria, L. I., N. Y.
10595 Wallower, C. W., Buffalo, N. Y.
10596 Wolferstan, S.H.P., Montreal, Que.
10597 Wortman, O., Pittsburg, Pa.
10598 Zschokelt, C. G., San Francisco.
10599 Deming, L. F., Philadelphia, Pa.
10600 Elsman, R., San Francisco, Cal.
10601 Steele, E. H., Fruitvale, Cal.
10602 Tupper, H. B., Los Angeles, Cal.
10603 Johnson, F. E., Mansfield, O.
10604 McKenney, L., Wappingers Falls N. Y.
10605 Montgomery, T. D., N. Y. City.
10606 Reynolds, W. H., Winnipeg, Man
10607 Wickman, J. H., Memphis, Tenn.
10608 Stokes, H. R., New York City.
10609 Reinke, A. E., Berlin, Germany.
10610 Ritchie, R. R., Oklahoma City, Okla.
10611 Murray, J. D., Chicago, Ill.
10612 Leibold, C. P., Columbus, O.
10613 Hall, H. M., Massena, N. Y.
10614 Abbott, L. W., Boston, Mass.
10615 Alder, F. W., Oakland, Cal.
10616 Chapman, C. H., Schenectady, N. Y.
10617 Drake, R. W., Chicago, Ill.
10618 Hayer, Ole S., Brooklyn, N. Y.
10619 Isbister, J., Victoria Mines, Ont.
10620 Lowry, J. E., Edmonton, Alta.
10621 Smith, H. A., Pittsfield, Mass.
10622 Busby, N. J., Jr., Boston. Mass.
10623 Riebel, F., Jr,, Bedford, Ind.

Total, 42.

Recommended for Transfer

The following Associates were recommended for transfer by the Board of Examiners at its regular monthly meeting held on July 26, 1911, and the names of the applicants will be presented to the Board of Directors for final action in regular course. Any objection to the transfer of any of these Associates should be filed at once with the Secretary.

GEORGE L, KNIGHT, Designing Engineer, Brooklyn Edison Company, Brooklyn, N. Y.

LEO A. PHILLIPS, Asst. Chief Engineer, Allis-Chalmers Co., Milwaukee, Wis.

LOUIS E. BOGEN, Chief Estimating Engineer, Allis-Chalmers Co., Milwaukee, Wis.

A. S. MILLER, President, Union Electric Light and Power Co., St. Louis, Mo.

J. G. WRAY, Chief Engineer, Chicago Telephone Co., Chicago, Ill.

MARKHAM CHEEVER, In charge of Chief Engineer's Office, Telluride Power Co., Provo, Utah.

WILLIAM G. CHACE, Partner, Smith, Kerry and Chace, Winnipeg, Man.

Advanced Study in Electrical Engineering at Massachusetts Institute of Technology

The just completed year at the Massachusetts Institute of Technology has found the graduate study which is provided in electrical engineering with an increasing number of students. Professor Jackson's lectures on the organization and administration of public service companies were attended by a class of twelve graduate students and Professor Pender's lectures on advanced alternating currents and the transmission of power were attended by an even larger number of graduate

Digitized by Google

students. Professor Wickenden's advanced course in the design of central stations and distribution systems has also been in demand. Besides graduating the largest class from the undergraduate course which the Institute of Technology has heretofore graduated in electrical engineering, one degree of Doctor of Engineering and four degrees of Master of Science were conferred on men taking their major work in electrical engineering.

The applicants for permission to become candidates for advanced degrees in electrical engineering are already more numerous than they were last year, and particularly is this true in respect to graduate students who intend to study the problems of electric railroads, electric transmission of power and the organization and management of public service companies.

The electrical engineering department of the Institute of Technology received an appropriation of $3,000 from a prominent electric illuminating company of Boston, to be used in an investigation of the relative operating reliability and costs of electric trucks, gasoline trucks and horse trucking, for the purpose of determining to what degree electric trucks are adapted to compete with gas and horse trucks in the city of Boston. This investigation will cover the cost of delivery of goods in the different ways. It will include all questions which concern electric trucks, including the influence of the different kinds of city pavements on cost of delivering goods, and the effects of different routings of the vehicles. The investigation will be partly theoretical but it will be planned to determine practically what it ordinarily costs to deliver goods under city conditions. This part of the investigation will be accompanied by actual observations extended over a period of many months. At least a year will be occupied in this work, and Mr. H. F. Thomson has been appointed Research Associate to carry on the work under the direction of Professor Pender.

Past Section Meetings

Fort Wayne

A special meeting of the Fort Wayne Section was held on Monday evening, June 5, in order that the members might hear a lecture by Mr. W. D. A. Ryan, of the General Electric Company, Schenectady, on "Modern Illumination." Notwithstanding the heat, 85 members and guests were present at the lecture, which was particularly opportune due to a recent municipal controversy on the subject of street lighting. Mr. Ryan was introduced by Chairman E. A. Wagner, and after a review of the history of lighting, he took up in detail all matters pertaining to the general development of the modern arc lamp, showing the increasing light efficiency with each successive stage of development. This was illustrated with candle-power diagrams which were thoroughly explained for the benefit of the non-technical men in the audience. A number of the different types of arc lamps were arranged with lenses projecting a view of the electrodes on the screen in such a manner that the action of the electrodes in meeting and forming an arc and crater could be shown in a most interesting manner. The problem of ornamental street lighting was also discussed, and lastly, Mr. Ryan gave a full description of the wonderful electrical effects produced at the Hudson-Fulton celebration.

Among the audience were a number of members of the Commercial Club, the Retail Merchants Association, and the Electro-Technic Club, all of whom had been invited to attend this meeting. The lecture was profusely illustrated by lantern slides.

The annual meeting of the Section was held on June 15, and was preceded by an informal dinner at the Fort Wayne Commercial Club. After a discussion of several questions relating to the conduct of the Institute and Sections, the following officers were elected to serve during the ensuing year:

Digitized by Google

Chairman, E. A. Wagner; vice-chairman, T. W. Behan; secretary, J. V. Hunter; directors, E. A. Barnes, H. L. Browning, M. J. Kehoe.

Ithaca

One of the most successful banquets in the history of the Ithaca Section was held in the library of the Sibley Dome on May 25. As is customary at the Section banquets, a number of ingenious electrical surprises were prepared for those present. Upon entering, one passed between two Christmas trees placed so close together as to necessitate brushing against them. Minute electric sparks on the shoulders from the trees caused every man to start as he passed between the trees. Another electrical feature was the receipt of telegrams from famous deceased scientists. The menu was printed in the continental telegraphic code for the edification of those but slightly familiar with it. Professor Nichols, head of the physics department, acted as toastmaster. Dean Smith was the first speaker, and he " broke the ice " with an appropriate speech. Other faculty speakers were Professors Karapetoff and Norris. Interesting features were introduced between the speeches. The guest of honor was Mr. P. M. Lincoln, of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa., who gave an inspiring speech for young men entering the engineering profession. Professor Macomber, on behalf of the Institute, presented a picture of Dr. C. P. Steinmetz to Sibley College. The picture was accepted by Dean Smith with a suitable speech of acknowledgement. Mr. M. W. Alexander, of the General Electric Company gave a brief talk on the relation that should exist between the college and the industrial corporations in the training of young engineers.

Mexico

A successful semi-social meeting was held by the Mexico Section on June 9, when 26 members gathered at dinner in the dining room of the Hotel Iturbide, City of Mexico. Mr. W. B. Hale presided and read a paper on " Tariffs for Electric Energy ", by Chairman Leonarz, who was unavoidably absent. The paper was discussed by Messrs. H. G. Fenton, A. E. Reynolds, H. S. Foley, E. T. Bailey, H. C. Hawkins, H. B. Corning, and W. B. Hale.

San Francisco

By invitation of Mr. A. H. Babcock, electrical engineer for the Southern Pacific Company, the San Francisco Section held its regular monthly meeting in the Southern Pacific Company's new Fruitvale power plant on May 19, prior to the regular opening of the plant. Previously to the meeting a general inspection of the plant was made, various points of construction being explained by the particular engineers interested in each department. The meeting was then called to order and an interesting detailed description of the plant was given by various members of the engineering department of the Southern Pacific Company. A reprint of this description will be found in the *Journal of Electricity, Power and Gas*, issue of June 3. Several of the machines were inspected in detail, and after adjournment one of the large rotary converters was put into operation. One hundred and ninety-five members attended the meeting.

The annual meeting of the Section was held on June 23. The election for officers resulted as follows: Mr. W. A. Hillebrand and Mr. H. W. Crozier were elected as members of the executive committee for the two-year term beginning August 1, 1911, and Messrs. F. F. Barbour and S. B. Charters members for the one-year term. Owing to his removal to Chicago, Mr. S. G. McMeen tendered his resignation on the committee, which was accepted. Mr. McMeen's term would have expired on July 31, 1912. The holdover members for this year are Messrs. S. G. McMeen and H. A. Lardner.

Digitized by Google

At the close of the business session a paper on "Illumination" was read by Mr. L. S. Twomey.

SCHENECTADY

The Schenectady Section held its final meeting for the season of 1910–1911 on May 9, and was addressed by Mr. W. C. Fish, manager of the General Electric Company's Lynn works. Mr. Fish's subject was "The Relative Advantages of Small and Large Manufacturing Establishments." Mr. Fish dealt with the subject entirely from the factory cost point of view, taking up three items; material, labor, and general expense. He held that in these three particulars the large establishment occupies no advantageous position, on account of its size. With regard to the general expense account which it is popularly supposed can be kept proportionally low in a large establishment, instances were mentioned where doubling the output effected a saving of only one or two per cent on the cost of the finished product. It was pointed out that the reason manufacturers have for seeking large orders is to keep a full shop working full time. Attention was also drawn to the fact that in a large concern there may be a greater possibility of waste and that this waste is more difficult to detect. About 250 members were present.

Personal

MR. NORMAN READ has been appointed electrical engineer with the Denver City Tramway Company, Denver, Colo.

MR. C. R. UNDERHILL is now associated with the Acme Wire Company, New Haven, Conn., as electrical engineer.

MR. CHARLES D. COLE has been placed in charge of the Oswego River Power Company's lines and substations, with headquarters at Fulton, N. Y.

MR. M. W. BUCHANAN, formerly expert electrical aid, Bureau of Construction and Repair, Navy Department, Washington, D. C., is now with the Diehl Manufacturing Company, Elizabethport, N. J.

MR. G. S. MALTHA, after a two-year stay abroad, has returned to this country, and has accepted a position as mechanical engineer in the works-engineering department of the Western Electric Company, at Hawthorne, Ill.

MR. R. H. FENKHAUSEN, who for the past six years has been chief electrician at the Risdon Iron and Locomotive Works, has entered the service of the Union Iron Works Company, of San Francisco, as electrical engineer.

MR. W. K. FREUDENBERGER, formerly electrical engineer for the Steptoe Valley Smelting and Mining Company, McGill, Nevada, has been appointed expert engineer for the Public Service Commission of Nevada, at Carson City, Nev.

MR. ALEXANDER MACOMBER, of the engineering staff of the Tenney Syndicate, and formerly assistant to the electrical engineer, has been appointed electrical engineer for these properties, with headquarters at 201 Devonshire Street, Boston, Mass.

MR. C. E. HOGLE, hydroelectric engineer of the Porto Rico Irrigation Service, has resigned to accept a position in the office of the chief mechanical and electrical engineer of the United States Reclamation Service at Los Angeles, Cal.

MR. KIRK H. LOGAN, who for the past four years has been teacher of physics at the Kansas State Agricultural College, has resigned to become assistant physicist, Bureau of Standards, Washington. Mr. Logan will first undertake a study of electrolysis.

Digitized by Google

MR. F. C. SARGENT, formerly electrical engineer for the Tenny Syndicate, which controls and operated a number of gas and electric companies in New England and New York, has become engineering manager for these properties, with headquarters, as formerly, at 201 Devonshire Street, Boston, Mass.

Obituary

MR. WILLIAM R. BRIXEY, of the Kerite Insulated Wire and Cable Company, New York City, died suddenly at Milford, Conn., on June 9. Mr. Brixey was born in Southampton, England, on May 11, 1851. After leaving school he entered the British Mercantile Service, commanding his own ship, and visiting all the leading ports of the world. He came to this country in 1878 and went into business with his brother-in-law, Mr. A. G. Day, a pioneer in the American rubber industry and the inventor of kerite. In 1879 Mr. Brixey married Miss Francis N. DeWolfe, daughter of Alva G. DeWolfe, a co-worker of Mr. Day's and also an inventor of some note. The Day plant was at Seymour, Conn., and there Mr. Brixey developed the business with remarkable energy and intelligence, mastering it in every detail and becoming general manager on the death of Mr. Day, and sole proprietor on the death of his sister, Mrs. Day. Mr. Brixey was not satisfied with the use of his cables in the telegraph and telephone field or with the early endorsement of such men as Morse, but pushed out into larger developments in other fields. Noteworthy among these were the supplying and laying of the Alaskan cable, the furnishing of the Canal Zone cable, and the furnishing of the wires and cables for the Pennsylvania tunnel and terminal connecting the two shores of the Hudson and East Rivers. In 1908 Mr. Brixey incorporated the business as a company, and soon after retired, leaving it to the management of his eldest son, Mr. Richard D. Brixey, president of the Kerite Insulated Wire and Cable Company. Mr. Brixey left two other sons, Mr. Reginald W. Brixey, vice-president, and Mr. Austin D. Brixey, secretary of the company. Mr. Brixey was quite active in public life. Besides being an Associate of the Institute, he was a member of the Old Guard of New York City with the rank of captain, a member of the Brooklyn Club, and a high-degree Mason. Mr. Brixey's wife died in 1909, and he is survived only by the three sons mentioned. He became associated with the Institute on September 20, 1893.

MR. EDWARD MARION KENLY, an Associate of the Institute, died suddenly at North Yakima, Washington, on June 10, 1911. Mr. Kenly was born in Baltimore, Md., on June 15, 1867. He was educated in the public schools and he also took a three-year engineering course at the Baltimore City College. In 1895 he entered the employ of the Sparrow Point Electric Railway Company as constructing engineer. Subsequently he held the positions of mining engineer and superintendent of mines controlled by Mr. William H. Gorman, of Baltimore, general manager of the Montana Coal and Coke Company, and chief engineer of the Yakima Valley Transportation Company, North Yakima, Washington. Later he was made vice-president and general superintendent of this company and held these positions at the time of his death. Mr. Kenly was a member of the American Society of Civil Engineers. He was elected an Associate of the Institute on August 13, 1909.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Electrochemical Society. Transactions, Vol. 19, 1911. South Bethlehem, 1911. (Gift of American Electrochemical Society.)

American Institute of Architects. Proceedings of 44th Annual conven-

Digitized by Google

tion, 1910. Washington, 1911. (Exchange.)

American Railway Association. Proceedings of session held in New York City. May 17, 1911. N.p. n.d. (Gift of American Railway Association.)

Canada Commission of Conservation. Annual report 2d. Montreal, 1911. (Gift of Commission of Conservation.)

Centrifugal pumps, their design and construction. By L. C. Loewenstein and C. P. Crissey. New York, Van Nostrand, 1911. (Gift of Publishers.) Price, $4.50 net.

The best literature on the centrifugal pump has been published in other languages than English, although even abroad we find few complete and satisfactory works. The authors have made use of a large amount of the foreign material especially that in Neumann's "Zentrifugal Pumpen" and Lorenz's "Neue Theorie und Berechnung der Kreiselräder". The object of the present treatise is to furnish not only a description of commercial pumps but to discuss the theory, calculations necessary to secure the best efficiencies and performance, and the details of construction. W P.C.

Copper clad handbook, February, 1911. Chester, Duplex Metals Company, 1911. (Gift of F. F. Fowle).

Copper clad steel wire for automatic block signaling, report. By C. C. Rosenberg. New York, Duplex Metals Co., n.d. (Gift of F. F. Fowle.)

Copper clad steel wire for telegraph service, report June, 1911. Chester, Duplex Metals Co., 1911. (Gift of F. F. Fowle.)

Courants polyphases. By J. Rodet et Busquet. Paris, 1893. (Gift of V. L. Benedict.)

Dictionary of Electrical Engineering. Vols. 1–2. By H. M. Hobart. Philadelphia, J. B. Lippincott Co., n.d. (Purchase.)

Electric light for the farm. By N. H. Schneider. New York, Spon & Chamberlain, 1911. (Purchase.)

Elektrochemische Umformer (galvanische elemente). By Johannes Zacharias. Wien, 1911. (Purchase.)

International Catalogue of Scientific Literature. 8th Annual issue. D-chemistry. London, 1911. (Gift of E. D. Adams Fund.)

Massachusetts Gas and Electric Light Commissioners. Annual Report 26th. Boston, 1911. (Gift of Gas and Electric Light Commissioners.

National Fire Protection Association. Proceedings of 15th Annual Meeting, 1911. Boston, 1911. (Gift of National Fire Protection Association.)

New York Public Service Commission for the First District Report of a committee of the Board of Estimate and Apportionment. June 5, 1911. New York, 1911. (Exchange.)

Pennsylvania State Railroad Commission. In the matter of the complaints against the Philadelphia Rapid Transit Company. Report to the Commission by Ford, Bacon & Davis. Vols. 1–2, N.p., 1911. (Gift of Messrs. Ford, Bacon & Davis.)

Polytechnic Institute of Brooklyn. Catalogue of the College of Engineering, 1911–12. Brooklyn, n.d. (Gift of Polytechnic Institute of Brooklyn.)

Summary of report on the use of copper-clad steel wire in telegraph service to F. B. Chambers, Jr. By F. F. Fowle. Chicago, n.d. (Gift of F. F. Fowle.)

Telephone dispatching on the Great Northern. By Ed. E. Backus. Chester, Duplex Metals Co., n.d. (Gift of F. F. Fowle.)

Theorie und Berechnung der asynchronen Wechselstrom Motoren. By E. Arnold. Berlin, 1894. (Gift of V. L. Benedict.)

Traite theorique et pratique des courant alternatifs i industriels. Vols. 1–2. By F. Loppe and R. Bouquet. Paris, 1894, 1896. (Gift of V. L. Benedict.)

Digitized by Google

Water wireless telegraphy. By H. R. Khan. Allahabad, 1911. (Gift of author.)

Trade Catalogues

Crocker-Wheeler Co., Ampere, N. J. Bull. No. 126. Polyphase induction motors, constant speed. 15 pp.

——Bull. No. 128. Form W motors for rolling mills. 11 pp.

——Bull. No. 129. Direct current crane and hoist motors. 19 pp.

——Bull. No. 130. Small direct current generating sets. 3 pp.

——Bull. No. 131. Small direct current generator sets. 3 pp.

——Bull. No. 132. Form I machines, belt type, direct current. 15 pp.

——Bull. No. 133. Belt type a.c. generators two and three phase. 7 pp.

Cutler-Hammer Mfg. Co., Milwaukee, Wis. Elevator controllers and general control apparatus. 48 pp.

Fort Wayne Electric Works, Fort Wayne, Ind. Type A, form A oil transformers. 18 pp.

——Bull. No. 1127. Direct current grinders and buffers. 11 pp.

——Bull. No. 1128. Multiphase induction motor. 31 pp.

——Bull. No. 1129. Multiphase induction watthour meter. 11 pp.

General Electric Co., Schenectady, N. Y. Bull. No. 4820. Curve-drawing ammeters and voltmeters. 6 pp.

——Bull. No. 4821. Type F, form K-12, oil break switch. 15 pp.

——Bull. No. 4822. G. E.-98 railway motors. 17 pp.

——Bull. No. 4823. Type F, forms K-10 and K-15 oil break switches. 11 pp.

——Bull. No. 4826. G. E. water flow meter. 5 pp.

Leeds & Northrup Co., Phila., Pa. Moving coil galvanometers. 40 pp.

Ohio Brass Co., Mansfield, O. Catalogue No. 20. O. B. Catenary material. 86 pp.

Ohio Brass Co., Mansfield, Ohio. O-B. Bulletin, May-June, 1911, publishing news on electric railway and mine haulage supplies. 24 pp.

——Catalogue No. 8. Electric railway and mine haulage material. 297 pp.

——Catalogue No. 10. High tension porcelain insulators. 120 pp.

Pettingell-Andrews Co., Boston, Mass. Juice, June, 1911, giving information on electrical products. 16 pp.

Richard Heilbrun, Berlin, Germany. Electro-medical apparatus for doctors and hospitals. 67 pp.

Western Electric Co., Hawthorn, N. Y. Bull. No. 1003. Magneto convertible non-multiple switchboards. 23 pp.

Western Electric Co., Hawthorne, N. Y. Bull. No. 1080. Portable telephone sets for railway service. 55 pp.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa. Additions to perpetual catalogue No. 3001. 30 sheets.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa. Bull. No. 1191. Multiple and multiple series, metallic flame arc lamps. 11 pp.

——Bull. No. 1194. Engine driven d.c. interpole generators. 11 pp.

——Bull. No. 1512. Motor driven pumps. 42 pp.

Westinghouse Machine Co., East Pittsburg, Pa. New Model Roney mechanical stoker. 44 pp.

Wilson Maeulen Co., New York. Electric pyrometers. 12 pp.

——Table for conversion of centigrade to fahrenheit and vice versa. Melting points of elements. 2 pp.

United Engineering Society

Davis Handbook of the Porcupine Gold District. By H. P. Davis. New York, 1911. (Gift of author.)

International Waterways Commission. Report on Regulation of Lake Erie, 1910. Buffalo, 1910. (Gift of International Waterways Commission. American Section.)

Digitized by Google

Morton Memorial. A history of the Stevens Institute of Technology. Hoboken, 1905. (Gift of A. C. Humphreys.)

New York City Department of Health. Sanitary Code of the Board of Health. 1910. New York, 1910. (Gift of New York Department of Health.)

Patente-Jahres katalog XXII Jahrgang 1910. Brugg, 1911. (Purchase.)

New method calculating the cubic contents of excavations and embankments, by the aid of diagrams. Ed. 4. By J. C. Trautwine, Philadelphia, 1871. (Donor unknown.)

Preliminary report on the rock asphalt, asphaltite, petroleum, and natural gas in Oklahoma. (Bulletin No. 2, Oklahoma Geological Survey). Norman, 1911. (Gift of Oklahoma Geological Survey.)

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS B. STILLWELL. DUGALD C. JACKSON.

VICE-PRESIDENTS.

(Term expires July 31, 1912.)

MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

(Term expires July 31, 1913.)

DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
A. W. BERRESFORD.	H. H. BARNES, JR.	F. S. HUNTING.
WILLIAM S. MURRAY.	R. G. BLACK.	N. W. STORER.
HENRY H. NORRIS.	W. S. RUGG.	W. S. LEE.
SEVERN D. SPRONG.	C. E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **SECRETARY.**

GEORGE A. HAMILTON. RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.
*Deceased.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY GORDON STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L.A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russ

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	H. P. Wood.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor. Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, Wagner Electric Mfg. Co., St. Louis, Mo.
Toledo.....June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto.....Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana.....Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas.....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland.....Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College.....Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa Citv, Ia.
Kansas State Agr. Col. Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan,
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, Kansas University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute.....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oregon State Agr. Col.Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan. 26. '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, Cal 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

Digitized by Google

An Address delivered at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 27, 1911.

Copyright 1911. By A. I. E. E.
(*Subject to final revision for the Transactions.*)

ELECTRICAL ENGINEERS AND THE PUBLIC

PRESIDENT'S ADDRESS

BY DUGALD C. JACKSON

Members of the American Institute of Electrical Engineers are pleased to refer to electrical engineering as a Profession, and to the Institute itself as a Professional Society. When this occurs as a thoughtless repetition of fine sounding words, it has little meaning, since mere repetition of an alleged truth does not make it a real truth, and it can be established as a real truth only by tracing it to some adequate foundation. But when those statements arise from a ripe understanding that the word profession means more than a mere organized vocation for earning one's bread, it has a high and commendable meaning. The word profession "implies professed attainments in special knowledge, as distinguished from mere skill; a practical dealing with affairs, as distinguished from mere study or investigation; and an application of such knowledge to uses for others, as a vocation, as distinguished from its pursuit for one's own purposes." This sets the professional man in a position which demands from him an attitude of service and of leadership. He must have a masterly knowledge, in addition to skill in a vocation. He must deal practically in the affairs or needs of men. His duties must be performed with a touch of disinterested spirit in addition to the vocational spirit of earning his livelihood. Such men have a duty to the public; and in the performance of that duty they must exert their influence on that thought and practice of the day which affects the welfare and progress of the nation. We as electrical engineers cannot escape that duty in case we wish to maintain the professional character of our occupation.

It may be retorted that questions relating to the welfare and progress of the nation are matters of economics and sociology,

Digitized by Google

and not of engineering. The affirmation contained in this retort I will admit, but the negation I deny.

The theory of modern economics is built up under the influences produced by the introduction of steam power, with its potent agencies comprised in the steam railroad, ocean navigation, and the use of steam power in industrial operations. These agencies are the creatures of engineers. Watt, Stephenson, Fulton, Ericsson, Boulton, Arkwright, Nasmyth, Bessemer, Siemens, Corliss, Holley and the other fathers of our modern industrial economic conditions were engineers; and it would be folly to deny to the parents an interest in their offspring, and equally folly to assert that the further developments of economic theory are not largely dependent on those industrial changes which are continually produced by the inventive activities of the great body of engineers. When I speak of industrial operations or industrial conditions, it must be understood that I include among industrial affairs the great means for transportation and intercommunication which are comprised in railways, telegraphs and telephones, in addition to the manufacture and distribution of products which involve the application of mechanical power as distinguished from animal power, and the manufacture, accompanied by distribution by pipe or wire, of the media for providing illumination and power. The engineers have precipitated these affairs on the world by their inventions; these affairs are in a large measure the support of the engineering profession; and it is the duty of engineers to do their share in moulding their various economic creatures so that the creatures may reach the greatest practicable usefulness to society. In fact it would show a cowardly weakness to suggest that this duty should be avoided by men who are essentially responsible, as the engineers are, for the existing conditions. Theologians and physicians can practice their professions aloof from the ordinary affairs of the world, but the engineers associated with industrial events cannot. Moreover, such an avoidance of their duty by the engineers, even if avoidance of responsibility were possible, would be particularly unfortunate in view of the fact that the professed economists and sociologists apparently do not yet hold themselves subject to all the requirements of professional men, but still interpret their duties as being more confined to the field of study and investigation than to applying their knowledge to practical affairs.

It may again be retorted that the tenets which I am advocating will lead engineers out of a professional spirit and into

Digitized by Google

" commercialism ". It is worth while to pause here to reflect on that point. The word " commercialism " strictly means the characteristics of business or commercial life, but custom has made it applicable to any undue predominance of commercial ideas in a nation or community, and it has thereby come to infer a willingness to establish the strife for money in a position of precedence over reason and righteousness.

It has been alleged that learning loses of its dignity by becoming fashionable. It has also been alleged that learning loses of its dignity by becoming useful. Of the latter, at least, experience has proved the contrary,—happily for engineers who are proud of their profession, for engineering is necessarily an embodiment of the useful application of knowledge and learning. Engineering, relating, as it does, to the application of the powers of nature to useful purposes, must necessarily bring its followers into intimate contact with commercial affairs in an age when, as in ours, the industries dominate commerce, and the abatement of war has reduced the importance of military engineering. The tenets which I advocate do not tend to entangle the engineers in the depths of " commercialism " with which they may come in contact; but, on the contrary, those tenets propose that engineers should safeguard and nourish their professional spirit by assuming a part in public affairs in a spirit of disinterest, for the purpose of guiding the useful applications of natural forces to the greatest practicable service to society. A true engineer is a devoted follower after truth. He differs diametrically from the devotees of pure " commercialism ", who are strictly opportunists. He also differs from pure idealists, who are often notable for refusing to accept any advance unless it wholly meets their personal ideals. The spirit of the engineer rejoices in obtaining any move toward the truth, but is always seeking farther advance. This characteristic spirit has been manifested in men of great achievement in many walks of life. It is a part of the life of such men as Martin Luther, Gladstone and Lincoln.

Those who accept even in part the usual evolutionary doctrines which are summed up by Herbert Spencer in his view that progress occurs by successive differentiations and integrations producing development from the homogeneous to definite, coherent heterogeneity, will assent to the proposition that the modern giant corporation follows in the wake of the one-man business and the simple partnership in response to an inextinguishable natural law. This is a case of natural selection.

Digitized by Google

The progress of corporation development cannot be prevented. It is one of the manifestations accompanying improved means of speedy transportation and inter-communication. Of the influence of the latter agencies, a learned and distinguished historian says, "Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilization of our species. Every improvement of the means of locomotion benefits mankind morally and intellectually as well as materially, * * *." The possibility of, and indeed a necessity for, great corporate organizations came in the train of leading improvements in the means of locomotion and other beneficial inventions which abridge distance and subjugate time. Men of this age do not desire to relinquish the benefits of the improvements. We must, therefore, adjust our mental attitude to dealing properly with the situation; and in making the adjustment we must return to the old and approved recognition that a misdeed is a personal thing, and remember that responsibility for it cannot be shifted from the personality of the man in responsibility to an impersonal aggregation entitled a corporation which he manages. In early days when English kings had great prerogatives in the government, and the doctrine of divine right, associated with the doctrine that the king can do no wrong, were still extant, the king was nevertheless limited to an administration of the affairs of the realm conducted, history tells us, in accordance with the laws, and, in case he broke those laws, his advisers and agents were held responsible, and they were made personally answerable to the courts. History also indicates that this personal answerability of the advisers and agents had a tremendous influence on the conduct of government and its relations to the public. In building up our industrial structure we must not overlook the plain guide board of history, and personal answerability must be established. But if we must establish personal answerability to the public, we must also establish fair and generous dealing by the public.

The building up of a great industrial nation in an honorable state of civilization is subject to many hazards,—an error may cause injury to the structure that takes years or even decades to eradicate. It is, therefore, desirable to go cautiously and utilize the mature reflection of straight-thinking men who will give their thought to the subject. The forward route is untested, and real progress can be made only by judiciously combining teachings from the records of yesterday with experience of to-day to make a working theory for to-morrow. It has

Digitized by Google

been suggested that a theorist should be defined as a man who thinks he may learn to swim by sitting on the bank and watching a frog. Doubtless, there are many such men in the world, but they are not theorists. The definition is as inaccurate as defining a black object as an object without color. Such men are only inexperienced, superficial or foolish. Theory, as the word is used by engineers, means a working hypothesis founded on all known facts and experience, which may be used to guide progress beyond the margin of past experience. Every successful, progressive man is a constant user of theory in this proper sense of the term. Every progressive step is made according to a theory of the man responsible for the move. Theory is not antagonistic to practice but is founded on experience and is a guide to progress. Custom should be followed only when it has reason to support it. In the juncture now before us we must utilize the best theories of the corporation relations and the rights of persons and property, and cautiously extend our practices accordingly. No body of men are better equipped for this sound and scientific procedure than a body of professional engineers; and few others are so fully and adequately trained for such procedure as engineers, for the reason that this procedure is in accordance with the every-day steps of their business life. Moreover, the engineers of experience are well adapted to grapple with the mighty problems of a new age, for the reason that an efficient engineer must associate audacity and sobriety in his spirit.

If my premises are tenable, and I believe them to be incontestible, the engineers have a special duty, as professional men who are trained and experienced in straight thinking, to use their influence for the establishment and support of right and reason in the dealings between the public and the public service corporations. The problems surrounding the public service companies in American cities, and their relations to the citizens, should receive particular attention by members of our Institute, for those problems and those relations have been largely brought to their present importance and prominence through the activities of electrical engineers.

The public service corporations are the natural outcome of the demand of the civilized world for efficient and rapid transportation and intercommunication, and the concurrent need as communities become immersed in peaceful industrial pursuits for ample and conveniently provided supplies of water, gas and electric power. They compose a comparatively new and mighty force in the social organism and the organism must be

Digitized by Google

adapted to efficiently utilize this force, but the force must be prevented from dominating or warping the organism. There is no danger of the public service corporations becoming despots as some people seem to fear, provided they are put under proper restraints, but society cannot afford to make restraints which of themselves are unnecessary or unfair. These corporations serve a beneficial end in our life, and their rights are as well founded and should be as well secured and held sacred as the rights of any citizens who are individually or collectively bent on any proper business pursuits.

Some people seem to believe that all public service corporation men are either wicked or are liars or thieves. This has as little foundation in fact as a belief that all men in Spain carry mandolins or that Spanish women always wear mantillas. If such unjust, superficial and improper opinions are to have influence in this nation, then only misfortune and woe can be the outcome. It is necessary for all men trained in straight thinking to combat such folly and to cry out for fair dealing, one with the other, as between the public service corporations and the public which they are established to serve. No engineer does his duty who does not stand with fidelity for equally square treatment FOR as BY these corporations. These corporations are not here as vampires on society, but are here to serve the needs of the people in a reasonable and business-like way; and their proper objects cannot be accomplished unless thay are treated with reason and established in confidence. They obtain their income from serving the public, and they cannot give generous service unless they are granted generous opportunities. When under reasonable restraints and supervision, as by properly constituted public commissions, they are more quickly responsive to public sentiment than could reasonably be expected of any publicly owned business organization of equal magnitude which could exist under our political conditions, and their usefulness is proved beyond contradiction. Perhaps no man is more likely to observe these things than one whose professional practice, like that which has come to me, makes him retained adviser in some instances to public service companies and in other instances to governments or municipalities, for he has to study fairness to each class of clients in all he does.

A barrier of distrust which exists between these servitors of the people and the people which they serve is presumably due, on the one hand, to a memory by the public of misdeeds which were perpetrated before recent demands for reform brought

Digitized by Google

about the establishment of adequate public supervision in prominent centers, and to a fear of the repetition of misdeeds where supervision and publicity have not yet been prescribed; and, on the other hand, to a certain reluctance by corporation managers to exhibit full and convincing frankness for fear that such frankness may be made the opportunity by unscrupulous politicians or persons with interested motives to crowd them to the verge of insolvency. These particular conditions of distrust could be obviated by means of the public itself owning the public service properties and operating them in its own interest, but this is a drastic and undesirable alternative. Any fair-minded man of extended business experience who will study with unbiased intention the details of public ownership and public trading in the venerable and stable cities and states of continental Europe must be impressed with the reality that our inexpert and shifting governmental bodies are wholly unadapted to cope with such responsibilities, or to make an economic success equal on the average to that now accomplished by the privately managed service companies, whether the measure of success be taken on the basis of service provided for a unit of payment or on any other reasonable basis of comparison.

If the public could feel sure of the ingenuousness of corporation statements and statistics, and the corporations could be protected from unfair attacks made by ignorant, although, in many instances, educated, persons or persons with ulterior motives, the barrier of distrust to which I have referred would be dissipated as dampness is dissipated by the rays of the sun; but this cure requires a long step forward in the average line of progress, for it demands a supervision of the companies which imposes on them exact and ingenuous bookkeeping associated with the presentation to the public of accurate and luminous statements of their business, and it equally demands that the public shall be required to yield justice to the companies with the same ample fullness as individuals seek it for themselves. A progressive step of this nature is always accomplished slowly and hesitatingly. I have observed in Macaulay's writings a paragraph which is graphic in illustration of our present situation. "Everywhere," he says, "there is a class of men who cling with fondness to whatever is ancient, and who, even when convinced by overpowering reasons that innovation would be beneficial, consent to it with many misgivings and forebodings. We find also everywhere another class of men, sanguine in hope, bold in speculation, always press-

Digitized by Google

ing forward, quick to discern the imperfections of whatever exists, disposed to think lightly of the risks and inconveniences which attend improvements, and disposed to give every change credit for being an improvement. In the sentiments of both classes there is something to approve. But of both, the best specimens will be found not far from the common frontier. The extreme section of one class consists of bigoted dotards; the extreme section of the other consists of shallow and reckless empirics."

The public, misled or annoyed by the reluctance of some honest but overcautious managements to make frank public statements of financial results and present convincing statistics of operation, enraged by the acts of a few adventurers who from time to time have secured a speculative hold in the public service field, and enticed by the arguments of individuals with ulterior motives, are likely to follow the radical leadership of demagogues or of honest but false empirics. This is a danger which seriously exists in states where no public supervision of the service companies is provided, and also in a lesser degree in states where such supervision has been established. The danger must be rolled back by the exertions of fair-minded and right-thinking men. A serious menace to the welfare of the nation would be caused if unfair dealing toward the public service companies were established as a policy. A scrupulously frank and honest dealing with the public by the companies should be insisted on, but the public must be taught the importance of dealing on its part with an equally scrupulous fairness and a well-balanced generosity. It is here that I say lies a duty of electrical engineers to the public. It is to give of their time and brain to convincingly establish the facts (the *facts*, I repeat) which the public do not understand in regard to the business of the public service companies, to indicate the means for rightly treating these new influences which we and our fellow engineers have been creating by our works, and to aid in establishing measures which will favor and sustain mutual confidence and fair dealing between them and the public. This is an obscure and difficult problem on account of its touching the edge of men's ambitions and men's passions, and it seems at times to possess the opacity and insolubility of a mill-stone; but looking persistently and with care into what appears to be a mill-stone, not infrequently proves it to be composed of reasonably transparent material. The members of our Institute should take somewhat to themselves as professional men this obscure and difficult problem, and aid in its solution as a matter of their duty to the public.

Digitized by Google

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

PROBLEMS IN TELEPHONE TRAFFIC ENGINEERING

BY F. P. VALENTINE

It is the purpose of this paper to deal with a few of the many operating problems that confront a telephone company, serving a territory made up of several hundred communities of varying types ranging from a large Metropolitan area to sparsely settled rural districts.

A telephone company has but one line of good to sell, *i.e.*, service. The entire capital investment in telephone plant and all running expenses are for the purpose of handling the telephone traffic of its subscribers or customers, and from this service is derived the revenue of the company.

Under the prevailing form of telephone operating organization, the responsibility for handling the telephone traffic devolves upon the Traffic Department, which usually represents about one-half the employees and payroll expense of a telephone company.

In carrying out its duties, the traffic department has a two-fold responsibility; first, to the subscribers for the quality of the service that it renders to them; second, to the stockholders and subscribers for the economy with which it renders such service.

The quality of the service is directly dependent upon the effective application of suitable methods of operation. The effective application of suitable methods also bears directly upon the economy, for only by the use of such methods is it possible to obtain the maximum efficiency of force and plant. Further, both the quality and economy of service bear directly upon the satisfaction of the telephone user or customer. The quality should be such as to meet every reasonable requirement; the economy such as to enable the Company to supply service to

Digitized by Google

its customers at lowest possible rates compatible with a reasonable return on the investment, in order to encourage increase in subscriber development, thus constantly enhancing the value of the service to the individual subscriber.

To meet these requirements it is essential that a traffic department should have, in addition to a proper administrative force, an efficient traffic engineering staff. As the work of this staff is what might be termed the production engineering of the telephone business, it is obvious that it requires a qualitative and quantitative analysis of all factors in any way related to the production of telephone service.

The principal factors entering into the production of telephone service, which must be the subject of engineering study, are as follows:

1. Quality of service.
2. Efficiency of labor.
3. Efficiency of operating methods.
4. Production efficiency of central office equipment.
5. Production efficiency of trunk and toll circuits.

The following discussion of certain phases of traffic engineering problems, in the order above indicated, is based upon some of the results of studies made in the territory of the New England Telephone & Telegraph Company, as it is with the work in this territory that the writer is most familiar. This engineering work, however, is a part of and is carried on in conjunction with that of the engineering staff of the American Telephone & Telegraph Company, for the purpose of making comprehensive fundamental studies.

Quality of Service

From the standpoint of the telephone user, the essential qualities of telephone service are accuracy, speed of connection, and uniformity in both speed and methods of handling calls. These requirements are equally essential from the standpoint of the telephone company. Accuracy and speed of connection mean a minimum of waste effort, motion and time. Uniformity in speed and in the method of handling calls trains the telephone user to coöperate with the operator to the same end, with the resultant effect of satisfaction to the telephone user in smooth, speedy service, and for the Company a maximum production efficiency by the operating force and an economical use of switchboard equipment.

As the result of constant study there has been developed a

Digitized by Google

systematic method of service inspection which is now practically standardized among the larger operating companies. By means of suitable apparatus, observations are made on every step in the handling of a telephone call. By the use of stop watches the time intervals of each step in the operation are accurately observed and a code record made, sufficiently comprehensive to permit the analysis of the tabulated results of these observations. A sufficient number of calls is observed during the hours of regular traffic to insure the results being representative of the general grade of service being given in the office under observation. This service observation is practically continuous in all large exchange districts.

Equally careful analysis is made of the phraseology used by the operator in dealing with the subscriber. This latter is no small factor in accurate and speedy service. A telephone operator has to handle calls from subscribers of all types and characteristics and under all conditions. Every word and phrase used by the operator in dealing with a subscriber is the result of long and careful study and is designed to convey essential and significant information or direction in briefest possible form.

Another record essential to the analysis of service quality is what is termed the "record of service criticisms." This is especially valuable as it furnishes a record of the subscribers' opinions of the quality of service. This is a record not only of all formal complaints which are received, but also of data collected by all supervising employees in the central offices who have occasion to deal with any subscriber in connection with an abnormal telephone call. The record is made by noting in code, on a proper form, any comments received indicating the fact and nature of any unsatisfactory service that the subscriber has had, either then or at some previous time. Everyone of these cases is followed up and before the record is filed for summarizing, the reasons for the unsatisfactory condition are entered thereon. Besides affording an opportunity to adjust matters to the satisfaction of the subscribers, the analysis of these criticisms furnishes valuable data as to the most frequent causes of unfavorable opinion of service quality, and affords the opportunity of eliminating or minimizing these causes. It is of the utmost importance, not only as good business policy, but also to assist in the analysis of service quality, that every effort be made to obtain fair criticisms from the viewpoint of the customer.

Continuous study and analysis of the results of service ob-

Digitized by Google

servations together with the data obtained from the record of criticisms, has made possible the adoption of standard operating methods designed to give satisfactory service. All calls of abnormal type involving special handling, are transferred to special operators whose sole duty is to care for this class of traffic. This results in removing the most disturbing elements from the work of the " A " or subscribers' operators, and in providing special attention for such calls on the part of employees especially trained for that work.

The adoption of standard methods of operation and the setting of standards of speed and accuracy, has made it possible to reduce all operating procedure to standard sets of instructions for the guidance of all employees concerned. The tabulated results of service observations furnish the administrative force with the information as to how nearly the standards are attained, while the instructions furnish information as to how to attain them.

Efficiency of Labor

In determining the efficiency of labor, or the production efficiency of an operating force, it is necessary that standards of labor production be established, and that provision be made for significant reports or summaries which will indicate how nearly these standards are approached. It is not sufficient merely to compare results in various exchanges or in the same exchange at different times on the basis of the traffic handled regardless of the conditions attendant upon its handling. Such a comparison assumes to set as a standard the operation in some particular case. It assumes that at some other place or time an operation was performed with greater efficiency, and, therefore, it should be performed here or now at the same efficiency regardless of whether it is exactly the same proposition in both places or at both times.

The operation of a telephone switchboard comprehends the handling of many different kinds of traffic, and a separate standard is required for the handling of each. To express the degree of efficiency attained as a per cent of these various standards would not only be an interminable task but would give so many individual results that their study and co-relation would be impracticable.

It is necessary, therefore, that a method be employed which in a single percentage figure will show the degree of efficiency attained. This result is accomplished in the following way:

Digitized by Google

All calls handled are expressed as though they had been of a single class. This is done by multiplying the number of calls of each class by a factor representing the ratio of the labor of handling the calls of a particular class to the labor of handling calls of the class selected as the unit class.

The standard number of these unit calls which should be handled being determined, the per cent of efficiency is readily obtained by comparing the results obtained with those specified as a standard. From the foregoing, it will be seen that this method involves not only the selection of some unit, but the determination of the number of unit calls and the number of calls of other types that may be handled by average skilled operators within a given period, and the establishment of coefficients representing the ratio of the loads of each type of call to that of the unit class.

A flat rate non-trunked call handled on a No. 1 relay board was selected as the unit call for two reasons. It is a very simple type of call and one which predominates in number in most offices. Furthermore, it is of such a class of call that the number an operator can handle depends primarily upon her ability, and not upon circuit conditions.

The determination of the number of unit calls and the number of calls of other classes that operators could handle, involved a most exhaustive study of operating loads. This study consumed a period of over two years during which many thousands of observations were made covering all types of calls, normal and abnormal, from all classes of service. As a result of this study, it was found that an average skilled operator, working in a team of five or more operators, could carry 230 unit calls per hour and maintain that rate during the entire working day, without undue physical or nervous strain, at the same time giving a standard quality of service. Furthermore it was found that, for a single hour in each half day period an operator could, without material impairment of the service, handle 25 per cent more than this number. Even this load could be exceeded at times of unusually sharp peaks.

The ability of the force to carry the peaks at loads in excess of the average busy hour loads, is an important factor in determining operating force requirements. Fig. 1 shows in percentages the actual distribution of traffic in two offices for the day hours. The curve marked *A* is that of an office of the best type of residential subscribers, while the curve marked *B* is that of

Digitized by Google

an exclusively business office. The operators at A can carry the busy hour traffic at loads exceeding those of the average busy hours, while the operators at B will carry the standard load. With an equal amount of daily traffic in both offices, the same number of operators will handle the busy hour traffic of A as are required to handle the busy hour traffic of B.

In the evolution of this system of equating calls covering two years of exhaustive study and some four years of practical application, its value and accuracy have been thoroughly tested. Its value lies not only in the fact that it furnishes a means of measuring the efficiency of labor, and is essential in measuring the efficiency of some of the other four factors mentioned in open-

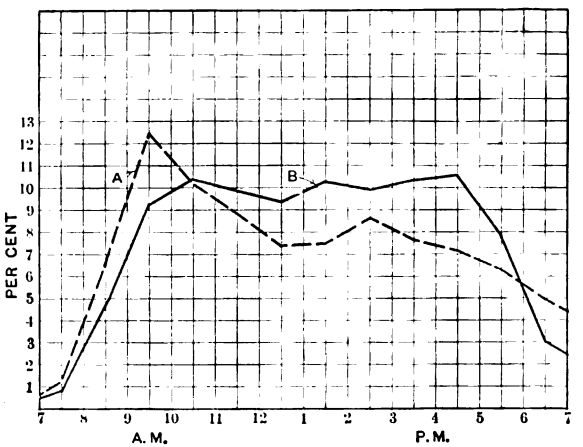


FIG. 1

ing this discussion, but in the fact that it has opened the way to a most exhaustive analytical study of the human element upon which telephone operation is so dependent.

As a result of the establishment of standards of service quality and labor efficiency, it has been possible to institute methods of selecting and training an operating force with a degree of success otherwise impossible. The question of fitness is of primary importance and the matter of intelligent selection of operators is the result of many years of careful study of the qualities essential to success. All accepted candidates for operating positions are required to spend one month in the operators' training school, listening to lectures in regard to the handling of all types of calls, with the necessary study and examination

Digitized by Google

hours, and in practical operating work under capable instructors on a regular working switchboard representing a typical central office, the calls being originated by instructors. No operator is allowed to work at a central office and handle the calls of telephone users until she has graduated from the school course and met a certain standard of requirement. With this training she has a thorough knowledge of how all classes of calls should be handled and only needs experience to settle that knowledge and acquire speed. This same course of training in modified form, is carried on in the smaller central offices where it is not economical to maintain a regular operators' school.

On an average it takes about a year for an operator to attain maximum efficiency. In view of the fact that, as in any large body of employees, there are constantly resignations and occasionally dismissals for cause, together with the steady growth in subscribers and traffic, it is obvious that the problem of maintaining at all times an adequate and suitably trained operating force, is very important one. Even with the most constant care in selection incompetency will develop in a certain percentage of the cases either during the school training course, or later, in the work in the central offices. On account of the reasons enumerated, it has been found that in order to produce a force of one year's average experience it has been necessary to start and partially train, or train and keep in service for a short period only, at least three for every one who stayed a year. As it costs over $200,000 per year to train central office operators in the territory of the New England Telephone and Telegraph Company, it is obvious that this is a problem well worthy of careful study.

In order to meet this problem, all conditions of employment and work have received most critical analysis. The operating loads have been most carefully determined having in mind the physical well being of an operating force. Working conditions have been made as pleasant and comfortable as possible. In addition to a liberal lunch hour, a fifteen minute relief period is insisted upon in the midst of each half day period. Commodious and tastefully furnished rest rooms are provided, magazines and periodicals supplied, and everything possible done to make the work attractive and free from excessive nervous strain. Vacations, with pay, are allowed once during each calendar year. To further the careful study of working conditions and of the human element as it enters into the problem, for over two years the

Digitized by Google

New England Company has employed a physician of highest standing to make a special study of all phases of these conditions.

A careful record is kept of each employee from the time she enters the service of the Company to the time she leaves. This record shows the character of the employee's work, comments of her superiors, results of service observations, and every detail that has a bearing on her efficiency. Such a record is essential in the determination of proper wage increases, and the record of reasons for resignation or dismissal is of especial value in the study of ways and means of maintaining a stable operating force.

This carefully studied system of selection, training and caring for employees, with adequate compensation for efficient work, based solely on merit, has had good results, as is indicated by the fact that during the past four years, it has been possible to increase the average length of employment of the operating forces by 20 per cent, while there is always a waiting list from which to select candidates. It would seem obvious, therefore, that as a large factor in the efficiency of labor the study of the development and maintenance of a proper operating force is essential.

Efficiency of Operating Methods

The efficiency of operating methods is in their adaptability to produce the required quality of service with the minimum of effort, labor and operating time per call, together with an economical use of switchboards, trunk and toll circuits.

The methods of handling local calls have been fairly uniform for a number of years, the greatest improvements having been made in specializing the operation for irregular calls, or those which cannot be completed at once by the *A* or subscriber's operator. Another step toward the application of efficient operating methods, brought about by the careful study of recent years, is the gradual elimination or diminution of abnormal types of service, such as heavily loaded party lines in congested centers, etc., which tend to degrade the quality and economy of service.

In the field of toll service, except in a few notable instances, progress was not as great up until comparatively recently. Toll services must be considered in two classes—"short-haul," or suburban toll, and "long-haul," or "long distance" toll. Within a comparatively short radius of most large telephonic centers are usually found a number of smaller communities closely related to the large center and with each other in a business and social way. The telephone traffic between such

Digitized by Google

offices is of the class first mentioned and usually constitutes a very substantial portion of the toll business, the traffic to more distant points, covered by the second class mentioned, being in the minority.

Toll operating methods have been the subject of most critical analysis for the past few years, resulting in the standardization of several different types of toll operation, each designed to be applied under given conditions.

The subject of operating methods is so fundamental to efficient operation in all its phases that it has received and is receiving very comprehensive study. Every suggestion must receive most careful and critical consideration in order to detect any inherent weakness and to guard against the introduction of a method which, while apparently harmless and even efficient under existing conditions, might fail to meet the requirements of a constantly increasing traffic.

So far as concerns the production efficiency of various operating methods, the use of the unit system, hereinbefore outlined, provided a means of determining the relative efficiency of the different methods. The effect of any change from one method to another can be predetermined by the application of the proper coefficients to the traffic involved.

Production Efficiency of Central Office Equipment

The amount of central office equipment necessary is directly dependent upon the number of equated or unit calls to be handled during the average busy hours, or, in other words, upon the number of employees for whom it is necessary to provide switchboard positions during the average busy hours. With service of standard quality, labor production at standard efficiency, and efficient operating methods, by use of the unit system applied to the amount of traffic to be handled, the switchboard requirements can be accurately determined. The discussion of operators' loads and Fig. 1 in the preceding section apply also to the determination of amount of switchboard.

In engineering central office equipment it is customary to engineer on a basis of a fifteen to twenty year ultimate capacity and to install initial equipment sufficient to cover from two and one-half to three years' growth. As it is necessary to know the ultimate requirements for buildings, etc., these are developed through special studies or "fundamental plans" which include the consideration of all factors that have a bearing on the future

Digitized by Google

development. In order to determine the probable growth in subscribers, it is necessary to maintain curves of growth for past years for each class of service sold. These curves are projected to the ultimate period, and corrected periodically from actual growth. With the curves of station growth is maintained a curve of the station calling rate in each class of service. From these records, supplemented by the yearly estimates of growth, can be determined the number of stations, and volume and type of traffic to be expected at any future period. By application of the equating process to the various classes of traffic and obtaining the number of unit calls to be handled, it is possible to forecast accurately the amount of switchboard required.

The production efficiency of central office equipment is determined by the output per position, or per dollar of investment. The unit system furnishes means of determining the relative efficiency of different types of switchboard for handling particular classes of service under given conditions. Given the desired standard quality of service, the production capacity of a given switchboard unit of any type can be predetermined, and actual results attained can be checked, by the proper use of the unit system. The relative economy of different types of boards must be balanced against other costs incidental to the case under consideration.

Production Efficiency of Trunk and Toll Circuits

The production efficiency of trunk and toll circuits is affected by the quality of service which it is desired to produce, by the efficiency of operating labor, and by the efficiency of operating methods, and to a certain degree, by the efficiency of central office equipment. It is also affected by the volume of traffic to be handled and the contract conditions under which the service is sold.

Analysis of this subject has demonstrated that while operating and equipment costs very directly with the number of unit calls, circuit costs very indirectly with the number of calls, due to the varying efficiency of circuits in groups of different sizes, and more or less directly with the length of haul under a given amount of traffic, except so far as qualified by variation in type of plant necessary to meet transmission requirements.

The production capacity of a circuit under any method of operation, is determined by the average circuit holding time per call and the number of calls to be handled over the particular group of circuits in a given time.

Digitized by Google

For proper consideration of the subject of circuits, distinction will be made between trunk and toll circuits. Trunk circuits may be considered as local circuits connecting offices covering an area of too great telephonic density to be served economically from one central office, and in which case local service, so called, is sold covering intercommunication between the several central offices. Toll circuits will be defined as circuits between offices more distant from each other and between which the service is sold on a message basis, the charge being graded according to duration of connection and distance involved.

Toll circuits, however, must be considered in two classes, one embracing the " short-haul " or suburban toll traffic, and the other the " long-haul " or " long distance " traffic. The former class may be considered on the same basis as trunk circuits, so far as concerns production efficiency and engineering.

The trunk circuits and " short-haul " toll circuits are provided for the purpose of handling calls on a local basis; that is, the telephone subscriber passes the desired number to his operator and remains at the telephone until the connection is completed or a report returned to him of inability to complete. This feature of the trunk and " short-haul " toll operation necessitates providing a sufficient number of circuits between two offices to handle the traffic offered during the busiest period so that there is always a circuit available when a call is to be handled.

The " long-haul " circuits are for economical reasons provided on a less liberal basis which contemplates that the calls will not be handled while the subscriber remains at his telephone.

A comprehensive series of studies on the subject of circuit use has resulted in the development of methods by the use of which all the elements entering into circuit use can be given proper consideration, and the most efficient operating methods applied to existing conditions.

In figuring circuit loads, as a matter of convenience, it is usual to consider the load for a given group of circuits, rather than for a single circuit. As the circuit holding time is made up the time of conversation plus the use of the line for operating purposes, the total holding time for a call will differ according to the operating method used; for example, the local or " short-haul " toll requires less holding time than that handled on the " long-haul " basis. Also the efficiency of the individual circuits increases as the size of the group increases. These various factors have been studied and reduced to known quantities.

Digitized by Google

Having ascertained the production capacity of circuits under various conditions of volume of traffic and methods of operation, it is possible to set the proper standards to apply, and with which to check actual results, so far as concerns individual groups of circuits. The study of this matter, however, has developed the fact that in order to properly engineer the circuit plant for handling the traffic between several hundred offices, the subject is far more complex than would appear at first sight. In considering the circuit efficiency between two offices, as these same circuits may carry in addition the traffic to other points, the plant must be considered as a whole. The comprehensive study which has been referred to, has developed methods by which the circuit plant can be intelligently laid out with predetermined results. The problem in laying out a circuit plant is to furnish the proper standard of service as to accuracy, speed and transmission, with a minimum investment in line plant. It is obvious when one considers the variety of types and grades of trunks and toll circuits that this is no small matter.

The production efficiency of a trunk and toll circuit plant has usually been figured either by computing the number of calls handled per circuit or the earnings per circuit mile. Neither of these methods, however, gives the true measure of circuit production efficiency, inasmuch as for economical reasons it is often necessary to switch long-haul calls through one or more intermediate offices, and on account of the varying size of the circuit groups and the consequent variation in the capacity of individual circuits, the real production efficiency of the circuits cannot thus readily be determined. On the other hand, comparison of the earnings per circuit mile would be very misleading if any change in rates had been made between the periods under consideration.

A far more logical means of measuring the production efficiency of a trunk and toll circuit plant is afforded by computing the number of message miles produced per circuit mile. By computing the former on a basis of air line measurements between points of connection and the latter on the basis of actual circuit route mileage, a means is afforded of checking the efficiency of circuit plant layout, not only from the standpoint of the efficiency of labor and methods, but also from the standpoint of economical plant layout.

In the foregoing sections there have been discussed in a somewhat incomplete way, some of the principal factors entering into

Digitized by Google

the consideration of traffic engineering problems. Each of these factors has involved most comprehensive study, a discussion of which would involve a paper of considerable length. There is a close relation and inter-dependence between them all. The quality of service is affected by all the other factors, and itself has to be considered in connection with each one. To illustrate the complexity of the problems, and to indicate the possibilities in construction application of the principles deduced from their comprehensive analysis, it is proposed to discuss the concrete application of some of the results of the engineering studies of the last few years in the development of a toll operating system and plant.

From the standpoint of the telephone user, the ideal toll service would afford connection with the most distant point with substantially the same celerity as obtains in case of a local connection. The development of a toll operating system should be toward this ideal as far as economically consistent.

The handling of toll business at special toll boards, or at separate positions on the local board, developed for two reasons. While the operating and equipment charges, under a given toll operating method, are fairly constant, the circuit charges increase in weight with the length of haul. In view of the large investment involved in long toll circuits, it was deemed necessary for economical reasons, to make each circuit handle all the messages possible, and it was generally customary to handle such calls on the basis of arranging to have both parties ready to talk before the circuits were put up for the actual conversation. From the nature of operating procedure involved in handling traffic on such a basis, it was obviously necessary to remove the handling of this type of call, involving extra labor, from the *A* or subscriber's operator, as it would, if handled by the latter, prevent the smooth, quick answering and handling of local connections. Further, on account of the extra labor involved, the productive efficiency of the operator and switchboard were very substantially reduced. It was therefore necessary to specialize and segregate this business. Where the local board was of fair size or an expensive multiple board, it was economical to set up an entirely separate board carrying only the toll circuits, the connection with local subscribers being made through the medium of switching circuits between the boards.

For a clear understanding of the explanation to follow, it will be well to briefly describe some of the most generally used methods of toll operation.

Digitized by Google

The operating methods employed in handling the toll traffic may be divided into two classes, "short-haul" and "long-haul". In the case of the "short haul" method the subscriber, who must pass his call by number, waits at his telephone until the called station answers, as he would on a local call. In the "long-haul" method, however, the subscriber, having given his call to a recording operator—specifying a particular party if he so desires—hangs up his receiver and waits for the toll operator to call him.

Calls of the latter class are further subdivided according to the operating method employed, namely, the two-ticket method, single ticket ring down method, and single ticket call circuit method.

Under the two-ticket method of toll operating the subscriber signals his local operator, asks for and is switched to the toll recording operator, to whom he passes information sufficient to insure the completion of his call, hangs up his receiver and waits to be called. The recording operator having written the necessary information on the toll ticket, forwards it to the line operator, who secures a toll line to the called office, rings, and when the inward operator answers, passes the details of the call, which are again recorded by the inward operator. The latter operator assumes the responsibility of obtaining the particular party; having done this she notifies the outward operator, who thereupon rings the calling subscriber. Both operators supervise and time the call, entering on the tickets the length of conversation and both are responsible for the prompt release of the toll circuits after conversation ends.

The single ticket ring down method of handling a toll call is the same as the two-ticket as far as the recording of the call is concerned and up to the time of passing the call by the outward operator. The latter does not pass the details of the call, but simply the called number to the inward operator, who, without making a second ticket, rings the desired number. The outward operator announces the call to the called subscriber, and assumes sole responsibility of timing and supervising the call, and of releasing the circuits after conversation ends.

The operation of the single ticket call circuit method is similar to the single ticket ring down. It is faster in that the outward operator secures the called station over call circuit trunks to a *B* switching operator in the distant office, thereby eliminating the services of an inward toll line operator.

Digitized by Google

The "short-haul" methods are subdivided into the "toll board" and the "*A-B*" method.

Under the former, the *A* or local operator receiving from the subscriber the number desired, passes the calling and called numbers directly to a toll line operator, thus eliminating the recording operator as a separate operator. The toll line operator records the call and after ordering the calling subscriber's line to be held on a trunk to the local switching operator, secures the called number as under the single ticket methods of operating.

Under the *A-B* method the toll operator is eliminated, the *A* operator recording the toll ticket and completing the call over a trunk to the distant office. She alone is responsible for

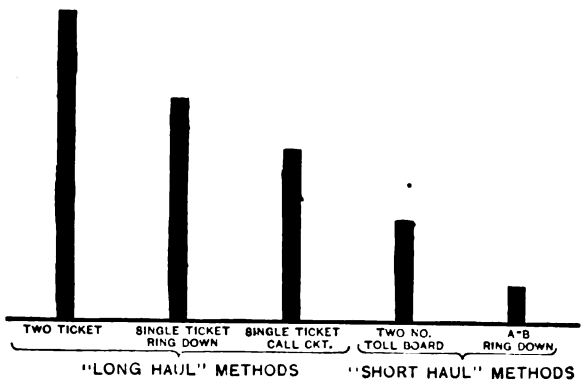


FIG. 2—Relative amount of operating labor required to handle a toll call by the various operating methods

supervising and timing the call. This *A-B* method may be on either a ring down or call circuit basis as may be most economical.

There are further refinements of these methods, in the way of "tandem" toll operation, etc., which are purposely omitted from this discussion, as it is impossible to go too much into detil, and the typical methods shown will serve to illustrate the processes described in the following:

Considering first the efficiency of labor involved in handling a toll call, Fig. 2 shows the relative requirements of operating labor under each of the above described methods.

Considering the production efficiency of central office equipment under the same operating methods, Fig. 3 shows the comparison of relative requirements in the way of switchboards and accessory equipment for the operation under each method.

Digitized by Google

It will be noted that in case of both the central office labor and central office equipment, the "short-haul" methods are relatively more economical than the "long-haul" methods. Bearing in mind that the toll circuit efficiency is affected by many variables, as has been explained, chiefly volume of traffic, length of haul and circuit holding time, it is necessary to consider this factor in connection with the efficiency of labor and equipment. Obviously, to handle traffic on a "short haul" basis, requires more circuits than to handle the same traffic on the "long-haul" basis. It is necessary, therefore, to ascertain under what conditions it will be economical to apply the more efficient operating methods, considering all factors involved.

The process by which the principles deduced from engineering

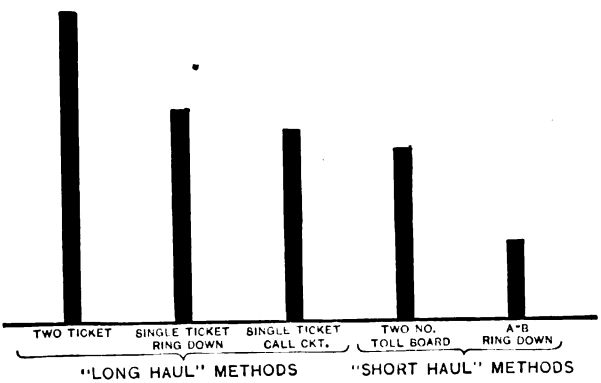


FIG. 3.—Relative amount of switchboard required to handle a toll call by the various operating methods

studies are applied to a territory involving a large number of offices of varying sizes and volumes of traffic, may be best illustrated by taking a hypothetical case, as shown in Fig. 4.

A and *B* are fair sized offices 30 miles apart. *C*, *D* and *E* are offices separated from *B* by 5, 8 and 20 miles respectively. *F* is between *A* and *B* and slightly off the direct line being 24 miles from *A* and 8 miles from *B*. The traffic between these offices is indicated in the table adjoining Plan 1. This traffic is shown in number of calls per day rather than per busy hour, for the sake of clearness. In the actual engineering, the busy hour loads are used.

It will be noted in Plan 1, Fig. 4, that the circuits are laid out in a way generally typical in past practice, the tendency being

Digitized by Google

to furnish direct circuits between points having a fair volume of daily traffic. Under this Plan 1, there are toll positions or toll boards at each of the offices. It will be noted that there are 14 circuits between *A* and *B* divided into several groups, also that there is a fair amount of traffic between *B* and *C* and *B* and *D*, with slightly less between *B* and *D*.

Under Plan 2, the traffic between *B* and *C*, *B* and *D* and *B* and *F*, has been taken from the toll position or toll board and is handled on the local boards on the "short-haul" *A*-*B* basis. *C*, *D*, *E* and *F* continue to handle their toll traffic with *A* on

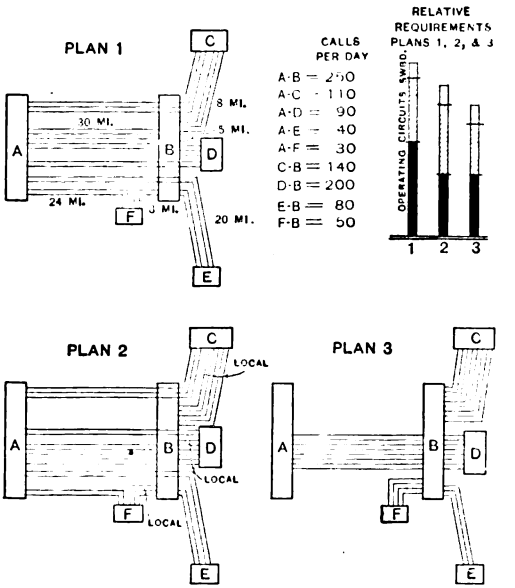


FIG. 4

toll positions and over direct circuits. At the right of Fig. 4 are shown the comparative requirements under the two plans. It will be noted that, in order to handle the traffic between *B* and *C*, *B* and *D* and *B* and *F* on a local basis through the local board, additional circuits had to be provided to place this traffic on a "short-haul" basis. This increased the circuit requirements, but made a material reduction in the operating requirements as shown, while the equipment requirements increased slightly owing to the transfer of the toll business to the more expensive local board. The composite result, however, is a substantial gain in economy.

Digitized by Google

Having placed the traffic between *B* and *C*, *B* and *E*, *B* and *D* and *B* and *F* on a "short-haul" operating basis, the way is open for still further modification. Plan 3, Fig. 4, shows the next step, which is the centering of all toll operation for *B*, *C*, *D*, *E* and *F* on the toll board at *B*. Placing the traffic between these tributary offices and *B* on a "short-haul" basis will permit of recording at *B* all toll calls from these points to *A*, practically without loss in time. The operators on the toll board at *B* can order up connections through toll switching operators at the tributary offices with the same efficiency and speed as with subscribers at *B*.

This plan, which has been termed "toll center operation", has several advantages. Applying the principles outlined in the section on the production efficiency of trunk and toll circuits, by combining into one group all toll circuits between *A* and *B*, each circuit can handle more calls than was the case where they were split into smaller groups as in Plan 1. The offices tributary to *B* receive practically local service with *B* and among themselves. They receive the benefits of the large team of toll operators at *B*, and the net result is a great improvement in the quality of service and greater economy in operating and in the use of equipment and circuits, as indicated in comparison No. 3 of "Relative Requirements". It will be noted that the circuits between *A* and *B* have been reduced from 14 to 8, while the total circuit mileage involved under Plans 1, 2 and 3 are 551, 620 and 436 miles respectively.

This hypothetical case illustrates the application of the engineering principles which have been outlined in the discussion of the various factors entering into efficient production. As indicating how substantially may be the results of the application of these principles to a large territory, it will be of interest to state that in the territory of the New England Telephone and Telegraph Company are over 730 central offices, nearly every one of which formerly had its own separate toll position or toll board, although in the smallest offices the toll operation was handled in combination with the local. The application of the above principles has been carried to the extent that to-day the toll traffic between these 730 offices is handled at 79 toll centers. The general effect on service has been, to place all short-haul traffic on an approximately forty second or better basis; to concentrate the longer haul high grade circuits in large groups between centers; to concentrate the long-haul toll operation at

Digitized by Google

these centres, with the increased economy and efficiency of a larger and more highly developed toll force; to remove from the small offices the burden of labor entailed in handling toll calls, this resulting in a smoother local service; and, through making available large groups of trunks on main routes, affording a more speedy, dependable long-haul toll service to all offices. Thus by the use of the comparative values established through development of the unit system of equating traffic and the establishment of standards of production efficiency for force, equipment and circuits, it has been possible to improve the quality of service, conserve the investment and reduce operating expenses.

Undoubtedly the most striking development in the analysis of the toll problem is that which has pointed out the way for the evolution and systematic development of the " short-haul " system of handling toll calls.

Reference has been made to the fact that from the viewpoint of the telephone user the ideal toll service would be that which afforded the same speed of connection to a distant point as that given in making a local connection. Having this ideal in mind, studies were made to determine to what extent this type of service could be developed economically. It was demonstrated that laws could be derived from these analyses whereby it could be predetermined, with a given volume of traffic and given average holding time per call, up to what point a suitable number and grade of circuits could be provided and furnish this type of service economically.

It was found essential, in order to furnish this " short-haul " toll service, that the calling subscriber should pass his call for the distant point by number and not for a designated party. This brought out two important factors as requisite to furnishing the means and the incentive to the subscriber for so placing his calls first, the matter of the telephone directory, that the subscriber might ascertain the number desired in the distant place; second, whether the subscriber could fairly be asked to place his call by number and pay for the connection if the distant station were reached, whether his party were there or not.

Investigation of the first factor showed that as the toll calls originated from a comparatively small proportion of the subscribers, where the amount of business warranted, directories for such other places as would meet the needs could be furnished without great expense, or special lists could be made up for subscribers doing considerable business with the distant points.

Digitized by Google

In case of the second factor, analysis of several thousand toll calls to points at varying distances from the originating office showed that in 89 per cent of the calls where the station was reached, the desired person either answered the telephone or was on the premises and available to talk, and that in 6 per cent more there was some one at the station with whom the business could be transacted. It was thus demonstrated that in 95 per cent of the calls, business could be successfully transacted. It further developed that there was less demand and necessity for locating a particular person on the short-haul calls than on the long haul calls, which is logical in that the more expensive long haul toll calls are not usually made unless the matter is of more importance than is the case in the ordinary short haul toll calls.

Based on these results, a plan was developed by which the " short-haul " traffic would be handled on an exclusively " two number-no delay " basis; while for greater distances, the particular person " long-haul " methods would be employed.

This plan has been gradually developed with the result that while in the year 1906 but 17 per cent of the toll traffic of the New England Company was handled on the " short-haul " basis, in 1910 over 50 per cent was handled on that basis, while the plans under development and already partially in effect for 1911, contemplate that by the end of the year at least 85 per cent of the toll traffic of the Company will be so handled. The results so far indicate that the telephone users greatly prefer this type of fast service to the slower " particular person " service and do not find it a serious disadvantage to forego the " particular person " privilege.

It is probable that the New England territory, with its great density of towns and cities, offers ideal conditions for the development of this type of service, but it seems reasonable to expect that the telephone using public generally, will eventually express preference for toll service of this character.

As the volume of traffic increases with the growth in the business, it will be possible to offer such service on an economical basis to a far greater extent than would seem possible without a full knowledge of the facts.

It is possible to obtain a view of some of the future possibilities in the development of " short-haul " toll service by examining the chart in Fig. 5.

The curve shown in Fig. 5 is one of a set of curves made up to

Digitized by Google

cover various conditions. The basic assumptions for this curve are, the use of No. 12 copper line circuit, common battery type of central office equipment, with standard operating, equipment and line production efficiency, and an eight hour telephone day: *i.e.*, one-eighth of the day's traffic is handled during the busiest hour.

The comparisons are between the generally used single ticket particular party "long-haul" method, and the "short-haul" *A-B* ring-down method. From this chart may be determined, assuming a given number of messages per day, up to what distance it will be possible to furnish enough circuits to permit of operating on the "short-haul" *A-B* ring down basis more

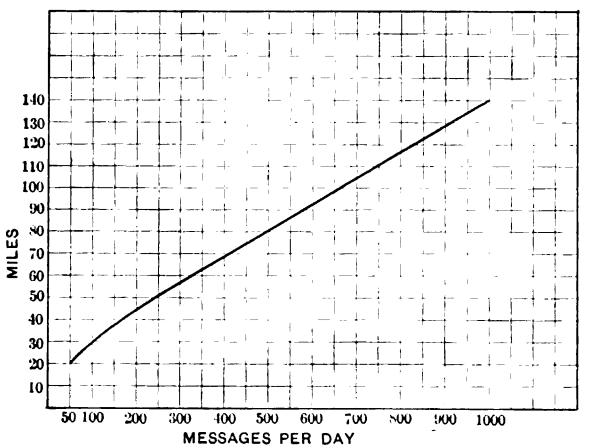


FIG. 5

economically than on the "long-haul" particular party single ticket basis. This takes into account all the factors involved that are necessary to a fair comparison.

It would seem obvious that once there is an appreciation of the latent possibilities developed by this analysis, there will be steady progress toward the development of this highly desirable type of service, which can be supplied economically in case of a substantial majority of the toll calls in a territory where there are a number of closely related communities within reasonable distance of each other.

The foregoing discussion has simply covered in a broad way a few of the important problems which have been the subject of

Digitized by Google

traffic engineering study for the past few years. The general problem of telephone service is so broad, and its full consideration involves so many and such a diversity of factors, that it is difficult, within the limits of a paper of this nature, to discuss comprehensively any one of its phases.

It should be apparent that the problems in connection with the production of telephone service are of sufficient importance to call for most careful analysis. The fact that the gross annual revenue of a telephone company is but a fraction of its capital investment, wherein it differs from most lines of commercial endeavor, makes such analysis a necessity. Solution of the problems of handling the traffic is fundamental to the construction engineering and equally so to intelligent consideration of matters affecting the economic end public policies of a telephone company. The determination of values in a problem affected by so many variables and the developments of simple methods of making use of them, have offered and still offer endless opportunities for a high grade of engineering.

The results of the studies so far made, have demonstrated that it is not necessary to rely solely on opinion or judgment from a certain point of view; that by analytical process many factors of apparently intangible values may be reduced to known quantities; that relations between them can be definitely and accurately established; and that from these relations certain laws can be derived which are capable of general application in the solution of telephone traffic problems.

Digitized by Google

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 28, 1911.

Copyright 1911. By A. I. E. E.
(*Subject to final revision for the Transactions.*)

ELECTRICAL OPERATION OF THE WEST JERSEY & SEASHORE RAILROAD

BY B. F. WOOD

The proceedings of our engineering societies abound in papers and discussions on the merits of steam and electric operation of railroads in which data are used, which to a large extent are lacking in figures taken from the actual cost of operation. A general impression prevails that operating officers of railroads will not consent to the publication of their operating costs. This to some extent may be true, but where such figures are correctly understood and properly used there should be no objection to their publication.

When the question of presenting certain data pertaining to the operation of the electrified portion of the West Jersey & Seashore Railroad before the American Institute of Electrical Engineers was discussed with the management of the Pennsylvania Railroad, the reply was made that not only would the information be furnished but that it would be a pleasure to have such information made public through the proceedings of the Institute. The following data were taken direct from the operating records with only such additions as would make them more readily understood. No effort has been made to curtail or to modify in any respect the data selected.

It is the object of this paper to present these data in as concrete form as possible without comparison with the operation of the parallel steam service, and no attempt will be made to analyze or compare the data with any that have heretofore been presented.

This paper will be of value if railroad engineers are encouraged to present before the Institute similar data, and if some standard

Digitized by Google

form for the compilation of such data is agreed upon. Comparisons could then be made more readily and their value enhanced.

It is hoped that a discussion will be developed which will

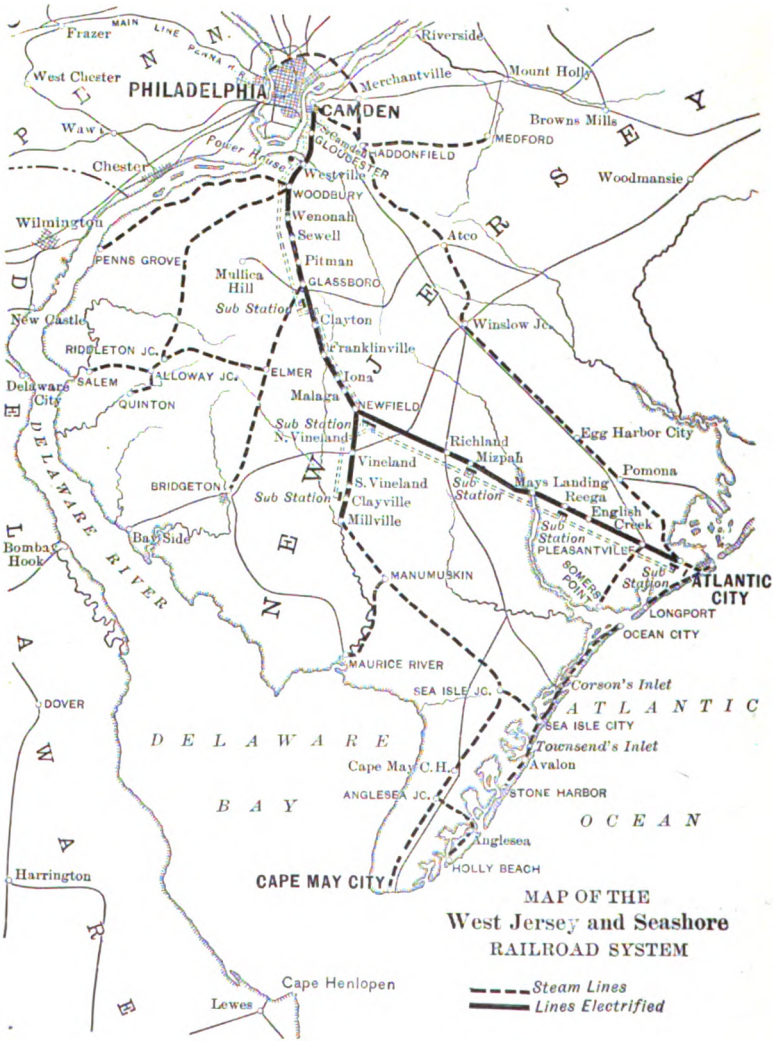


FIG. 1

enable operating officers and engineers to improve the efficiency, add to the reliability and reduce the costs of operation of electrically operated railroads.

Digitized by Google

No attempt will be made to describe in detail the construction used in the electrification of the West Jersey & Seashore Railroad as complete descriptions can be found by reference to the files of the Electric Railway Journal.[1]

The portion of the line which is electrically operated extends from Camden, via Newfield, to Atlantic City, a distance of 64.6 miles; and from Newfield to Millville, a distance of 10 miles. With the exception of the Millville Branch, which is a single track railroad, the line is double tracked with a third track extending for a distance of about six miles north from Woodbury.

This portion of the W. J. & S. R.R. was originally operated by steam and was a single track line south of Newfield. In the latter part of the year 1905 it was decided to electrify. The work was undertaken in December 1905 and had progressed to such a point that in the early part of July 1906 the first train was moved electrically. Regular operation by electric service was established in September of the same year.

The direct current over-running third-rail system operating at 675 volts was chosen for this installation.

A map of the West Jersey & Seashore Railroad is shown in Fig. 1, from which the electrified portion can be readily followed. The locations of the power station and the substations are shown, as well as the position of the transmission line with respect to the line of the railroad.

In order that the statements of cost of operation and detentions to train service may be more readily understood, the general characteristics of the electrified portion are given.

General Description

Track:

Main line, Camden to Newfield, double track, 100-lb. rails	30.2 miles
Main line, Newfield to Atlantic City, double track, 85-lb. rails	34.4 miles
Main line, South Camden to Woodbury, third track, 100-lb. rails	6.0 miles
Branch line, Newfield to Millville, single track, 100-lb. rails	10.0 miles
Total length of single track, including sidings	150.0 miles

Power Station:

Location: Westville, N. J., on Big Timber Creek, 5.6 miles from Camden Terminal. Rated capacity 8000 kw.

1. *Street Railway Journal*, November 10, 1906.
Street Railway Journal, October 12, 1907.

Digitized by Google

Equipment turbine room:
- Four 2000 kw. 6600 volt, three-phase, 25 cycle, Curtis turbo-generators.
- Twelve 700 kw. 6600/33000 volt, single-phase, 25 cycle, air blast transformers.
- Three 75 kw., 125 volt, Curtis turbo-exciters.
- Three 12 h.p. blowers, 20,000 cu. ft. per min. each.

Equipment auxiliary room:
- Four Williamson Bros. barometric condensers.
- Four I. P. Morris & Co., dry vacuum pumps.
- Four I. P. Morris & Co., centrifugal circulating pumps. (three driven by Reeve's engines; one by Curtis turbine).
- Two Cochrane feed water heaters, each 539 cu. ft. capacity to overflow.

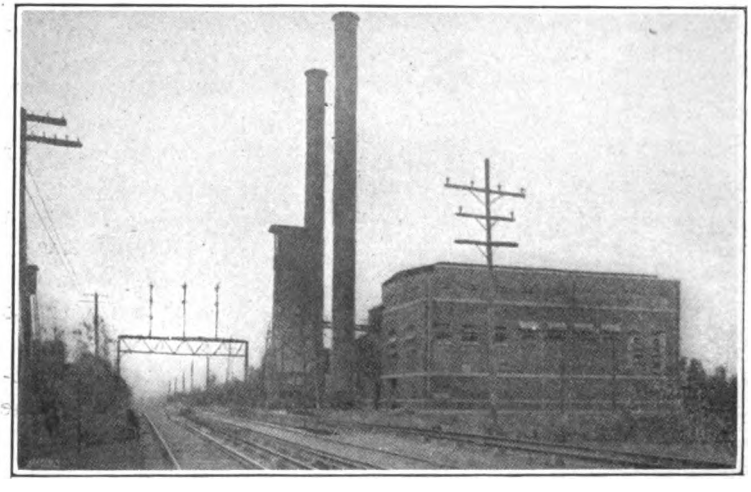


FIG. 2.—Power house at Westville, N. J.

- Three Worthington boiler feed pumps.
- Two Worthington make-up pumps.
- Two Worthington step bearing pumps.
- One R. D. Wood accumulator for step bearing, 800 lb. per sq. in., 100 gal. capacity.
- One R. D. Wood accumulator for step bearing, 100 lb. per sq. in.
- One Worthington oil pump.
- One Blake oil pump.

Equipment boiler room:
- Sixteen Sterling water tube boilers, 358 h.p. each, with superheaters
- Fourteen boilers equipped with Roney stokers.
- Two boilers equipped with Taylor stokers.
- Hunt gravity return system of coal handling used.

Digitized by Google

A general view of the exterior of the plant is shown in Fig. 2. In Fig. 3 a plan of the station is shown.

Transmission Line:

Length, 69.3 miles.

Line in duplicate, 33,000 volt, Y connected, neutral grounded.

Poles of chestnut, 45 ft. high, spaced 125 ft. apart—100 ft. at road crossings.

Head guys used every quarter mile, approximately.

Lightning protective ground wire strung on top of poles, 4 ft. above nearest wire, wire of 7 stranded steel galvanized cable, $\frac{5}{16}$ in. diameter. Grounded every fifth pole.

Two cross arms on each pole. Top arm 12 ft. long carries 4 insulators; lower arm 8 ft. 6 in. long carries 2 insulators. Insulators 42 in. apart, forming equilateral triangle.

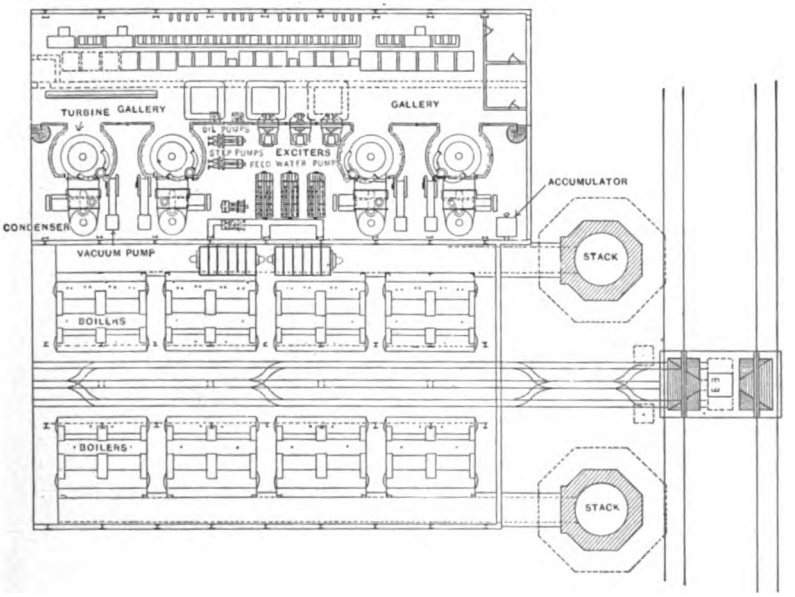


FIG. 3.—Plan of power house at Westville, N. J.

Wire, No. 1 B. & S., hard drawn, solid copper.

Wires transposed by one complete spiral between each substation, making a total of seven transpositions.

Signal line and lighting circuit, 1100 volt, single-phase, runs below 33,000 volt line from Camden to Newfield and from Pleasantville to Atlantic City.

Substations:

The high-tension, three-phase current is reduced in pressure and converted to direct-current at 675 volts in eight substations located as follows:

Digitized by Google

South Camden, 2.3 miles from Camden terminal.
Westville (in power house) 3.6 miles south from South Camden.
Glassboro, 12.1 miles south from Westville.
Newfield, 12.2 miles south from Glassboro.
Mizpah 10.9 miles south from Newfield.
Reega, 10.1 miles south from Mizpah.
Atlantic City, 12.5 miles south from Reega.
Clayville, 8.0 miles from Newfield (on Millville branch).

Equipment:

	Converters	Total cap.	Transformers	Alternating current line panels	Direct current feeder panels
South Camden	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	2
Westville	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	6
Glassboro...	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	4	4
Newfield....	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	6	5
Mizpah.....	Two 500-kw.	1000-kw.	Six 185-kw.	4	4
Reega.....	Two 750-kw.	1500-kw.	Six 275-kw.	4	4
Atlantic City	Two 750-kw. One 1000-kw.	2500-kw.	Six 275-kw. Three 370-kw.	2	4
Clayville....	Two 500-kw. One 1000-kw.	2000-kw.	Six 185-kw. Three 370-kw.	2	2

Converters, 6-phase, diametrically connected, started from alternating current end in three steps.
Transformers air cooled, placed over air duct, supplied by two blowers.
Automatic oil line switches.
Multigap lightning arresters in all stations.
The plan and section of a typical substation are shown respectively in Fig. 4 and 5. Fig. 6 shows the exterior of the substation at Newfield.

Third Rail:

Length, single rail, main line and branch.....137.12 miles
Sidings..... 4.61 miles

Total.....141.73 miles

Rails:
Standard P. R.R. cross section and composition, 100-lb. per yd.
Conductivity equal to that of copper rod of 1,200,000 cm. cross section. Located 2 ft. 2 in. from gauge line of track and 3½ in. higher than running rails.
Contact made on top of rail.

Digitized by Google

Bonded with concealed ribbon bonds, solid copper terminals, pressed into one inch holes drilled in the rail. Two bonds per joint, 500,000 cm. each.

Road crossing jumpers consist of one cable per rail, of 1,000,000 cm., in bituminized fibre conduit laid in concrete.

Jumpers brought out of concrete posts with removable hoods and bonded to rail by two stub-end bonds.

Third rails are provided with protection boards at all stations and for 20 ft. on each side of all road crossings. At stations side protection boards are also used. Top board, two in. plank, supported on castings held by maple posts placed six ft. apart.

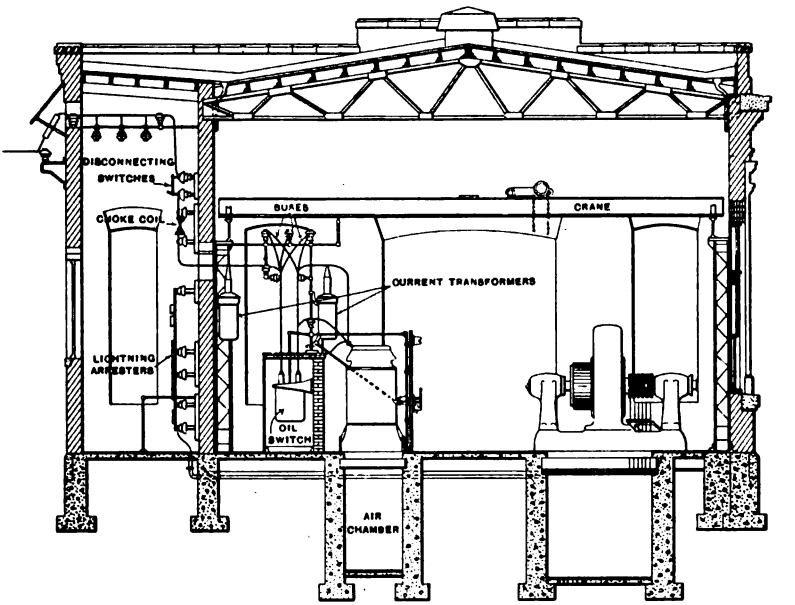


FIG. 4.—Transverse section of typical substation.

The third rails are sectionalized at each substation, each north-bound and each south-bound rail having a separate feeder.

The two rails are cross-bonded at three points between sub-stations.

No feeders are used in connection with third rail.

In Fig. 7 is shown a view of the third rail approach block, the top and side protection for the third rail.

In Fig. 8 is shown the third rail arrangement at cross-over and shows unprotected as well as protected rail.

In Fig. 9 is shown a general view of the yard at Camden, in which all of the third rail is protected.

Digitized by Google

Trolley:

Length of single wire,

Main line	8.60 miles
Sidings	0.04 miles
Overlapping	0.91 miles
Total	9.55 miles

Wire is No. 4/0 grooved section, supported by ⅜-in. galvanized steel stranded span wires at a height of 22 ft. above track rails.

There are two 750,000 cm. feeders, South Camden substation to Haddon Avenue, Camden, and one 500,000 cm. cable South Camden substation to South Gloucester.

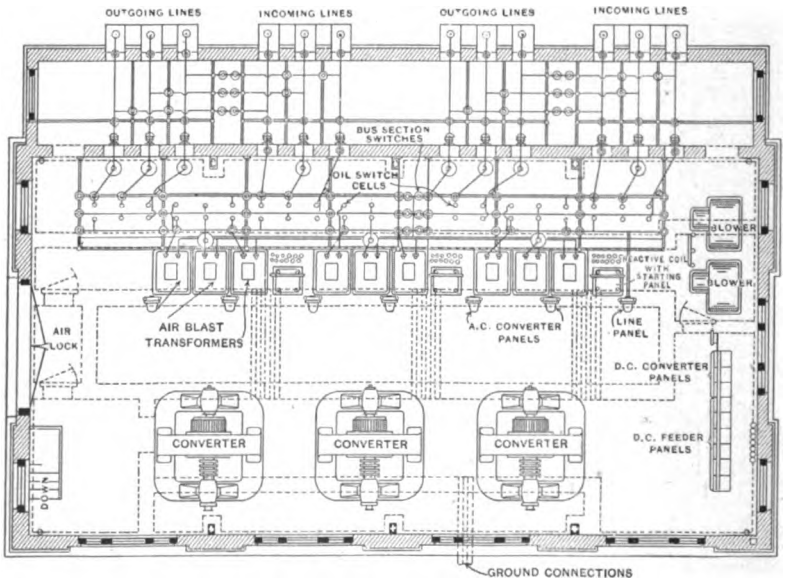


FIG. 5.—Plan of typical substation.

Track Bonding:

Concealed ribbon bonds used with solid copper terminals compressed into one inch holes drilled in the rail.

Two bonds per joint, 400,000 cm. each.

Special splice bars used to admit bonds.

Bonds tested every six months by means of millivoltmeters and Whitney Bond Tester.

Cars and Equipment:

Car equipment consists of:

79	coaches, seating capacity 58.
2	combined passenger and baggage, seating capacity 36.
6	baggage and mail.
6	baggage.
Total 93	cars.

Digitized by Google

Coaches weigh 94,500 lb. or 1,630 lb. per passenger.
Electrical equipment of each car consists of two 200 h.p. motors with multiple unit system of automatic control.
Gear ratio, 46:29.
Additional equipment has been authorized consisting of 15 steel

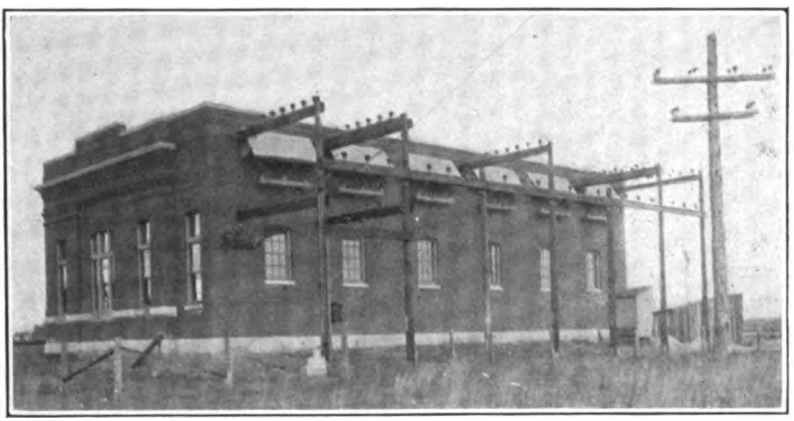


FIG. 6.—Exterior of Newfield substation

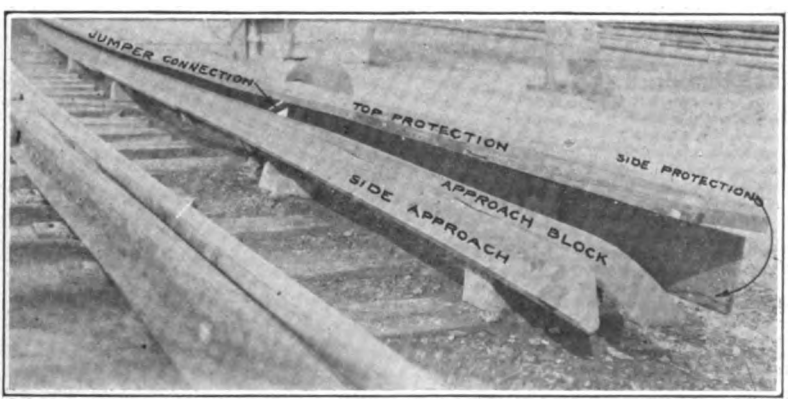


FIG. 7.—Third rail approach block, top protection and side protection

coaches, having a seating capacity of 72. The cars will weigh 103,500 lb. or 1445 lb. per passenger.

Inspection Sheds:

All inspections and repairs made in Camden shed. Other sheds used for emergency inspection and light repairs.

Digitized by Google

Camden shed, three tracks, accommodates 9 cars.
Atlantic City shed, two tracks, accommodates 6 cars.
Millville shed, one track, accommodates 3 cars.
Third rail is not continued into sheds, overhead trolly being used.

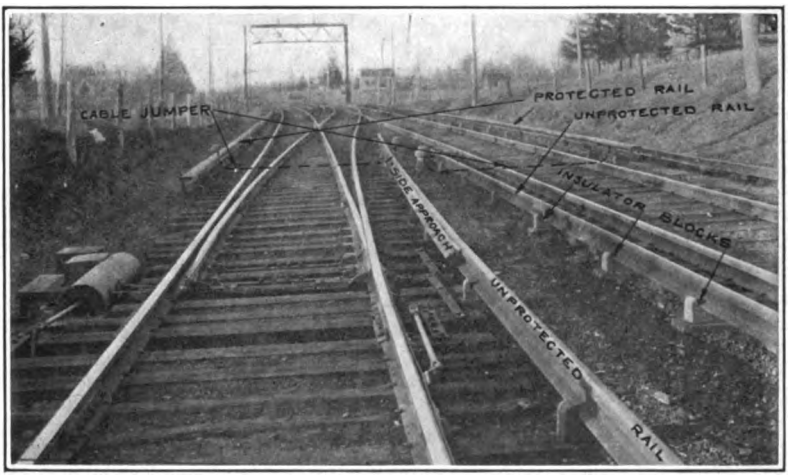


FIG. 8.—Third rail at cross-over

FIG. 9.—View of electrified yard at Camden terminal

COST OF CONSTRUCTION

A table is included showing the cost of construction in connection with the electrification and includes costs made necessary by electrification. It will be noted that the electrification

Digitized by Google

costs represent less than half of the total cost involved in the change of motive power.

Costs are also presented showing the unit costs of power station transmission line, substations etc.

COST OF CONSTRUCTION

Power Stations:		
Building, stacks, coal and ash handling machinery	$354,000	
Equipment	640,900	
Total		$994,900
Transmission line		241,500
Substations:		
Buildings	72,000	
Equipment	419,560	
Total		491,560
Third rail		557,636
Overhead trolley		80,500
Track bonding		102,659
Cars		1,135,900
Car repair and inspection sheds		46,674
Right-of-way, additional		592,100
Reconstructing tracks		763,800
Constructing new tracks		2,071,000
Terminal facilities and changes at stations		252,400
Signals and interlocking plants		561,900
Changing telegraph and adding telephone facilities		105,100
Fencing right-of-way, cattle guards, etc		88,400
Miscellaneous items		44,200
Total		8,130,229

UNIT COST OF ELECTRIFICATION

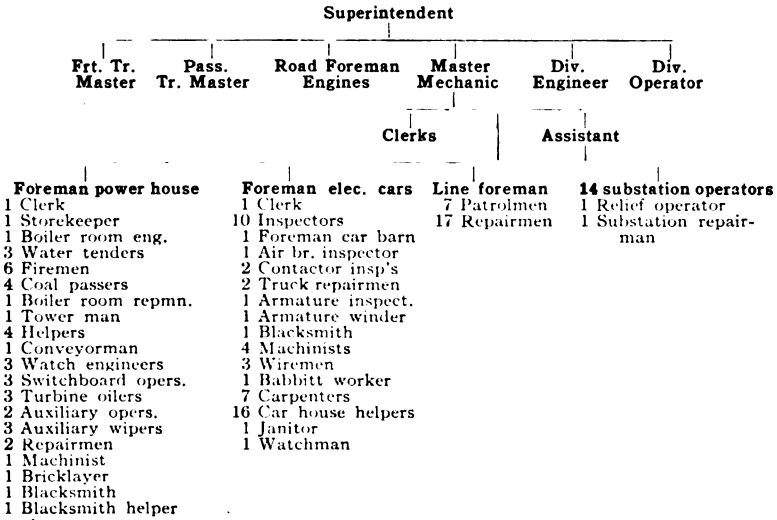
Power station, cost per kw	$124.36
Transmission line, cost per mile	3,485.00
Substations, building and equipment cost per kw	28.90
Third rail, cost per mile	4,235.00
Overhead trolley, cost per mile	4,120.00
Track bonding, cost per mile	684.50
Cars, including electrical equipment each	12,214.00

ORGANIZATION

With the introduction of the electric service the organization of the road was not changed but was expanded to provide for the new duties. A chart of the Motive Power Organization is

Digitized by Google

shown below, which shows the number of employees engaged in the various departments:



Cost of Operation and Maintenance

The cost of operation and maintenance is shown under several headings as follows:

1. Cost of operation in cents per car mile.
2. Cost of operation and maintenance of Westville power station.
3. Cost of maintenance of high-tension transmission line.
4. Cost of operation and maintenance of substations.
5. Cost of maintenance of third rail.
6. Cost of maintenance of trolley.
7. Cost of maintenance of bonding.

Table I shows the cost of operation for the years 1909 and 1910, in cents per car mile, and subdivides the cost of operation into the general headings, repairs, electric equipment of cars; repairs, passenger cars; other maintenance of equipment costs; electric power at car shoes; yard service, shifting cost; motormen; trainmen; train supplies and expenses; total of above; other expenses; total expenses. The table also shows the total car miles per month and the average cars per train. The headings of this statement are probably sufficiently explanatory, other than "other expenses," which includes cost of maintenance of way and structures, despatching trains, telephone and tele-

Digitized by Google

R STA

ents per -hr.

OPERATION	.047	
	.031	
	.005	
	.007	
	.090	
	.354	1
	.001	
	.002	
	.005	
	.004	
	.366	1
	.456	1
MAINTENANCE	.000	
	.004	
	.002	
	.003	
	.003	
	.002	
	.014	
	.000	
	.003	
	.001	
	.000	1
	.105	
	.000	
	.003	
	.112	1
	.126	1
SUMMARY	.104	2
	.478	12
	.582	15
	.007	
	.589	15

Average Cars per Train.
3.113
3.163
3.092
3.483
3.482
3.530
3.669
3.921
3.584
3.046
3.327
3.318
3.457
3.169
3.137
3.445
3.344
3.651
3.406
3.641
3.811
3.771
3.564
3.379
3.494
3.518

s and

of the
ement
n and

l and
ell as

ell as
on of

Digitized by Google

shown
the va

F
N

Foremar
1 Clerk
1 Storeke
1 Boiler
3 Water
6 Firemer
4 Coal pu
1 Boiler
1 Tower
4 Helpers
1 Convey
3 Watch
3 Switchl
3 Turbine
2 Auxilia
3 Auxilia
2 Repairr
1 Machin
1 Brickla
1 Blacksr
1 Blacksr

The
headin
1. C
2. C
statior
3. C
4. C
5. C
6. C
7. C
Tab
1910, i
into tl
repairs
electri
trainm
expens
miles
of this
than
of way

Digitized by Google

graph, crossing gatemen, together with traffic expenses and general expenses.

Table II shows the cost of operation and maintenance of the Westville power station for the year 1910. This statement is subdivided under the general headings of operation and

TABLE I
WEST JERSEY & SEASHORE RAILROAD
Electric train service
Passenger train statistics
Cost of operation in cents per car mile

	Repairs, Electric Equipment of Cars.	Repairs Passenger Cars.	Other Maintenance of Equipment Costs.	Electric Power at Car Shops.	Yard Service Shifting Costs	Motormen	Trainmen.	Train Supplies and Expenses.	Total.	Other Expenses	Total Expenses.	Car Miles, Total.	Average Cars per Train.
Year 1909													
January	1.06	2.05	0.48	4.78	0.51	0.93	1.53	1.20	12.53	10.25	22.78	279,210	3.113
February	1.07	2.42	0.38	4.63	0.51	0.91	1.49	1.22	12.63	10.99	23.62	258,130	3.163
March	1.18	1.97	0.35	4.99	0.52	0.99	1.65	1.18	12.83	10.17	23.00	279,193	3.092
April	1.26	2.03	0.25	4.43	0.46	0.89	1.40	0.61	11.32	9.14	20.46	317,963	3.483
May	0.84	1.73	0.26	3.98	0.44	0.88	1.45	0.45	10.03	9.18	19.21	318,006	3.482
June	0.40	0.68	0.31	3.58	0.25	0.86	1.41	0.42	7.91	9.35	17.26	339,294	3.530
July	0.33	0.44	0.12	2.82	0.20	0.80	1.25	0.40	6.36	6.95	13.31	478,203	3.669
August	0.28	0.40	0.14	2.75	0.20	0.75	1.18	0.36	6.06	6.29	12.35	517,223	3.921
September	0.43	0.67	0.14	2.75	0.25	0.83	1.32	0.42	6.81	6.87	13.68	428,571	3.584
October	0.64	0.71	0.24	3.84	0.31	0.92	1.53	0.62	8.81	10.21	19.02	307,825	3.046
November	0.52	0.39	0.29	3.85	0.29	0.95	1.70	0.82	8.81	9.30	18.15	291,816	3.327
December	0.87	1.08	0.29	12.31	0.30	1.00	1.72	1.30	18.87	15.05	33.92	292,175	3.318
Avg	0.68	1.10	0.25	4.30	0.33	0.88	1.44	0.69	9.67	9.08	18.75	4,107,609	3.457
Year 1910													
January	0.86	1.03	0.67	4.59	0.46	0.96	1.64	2.24	12.45	7.22	19.67	292,523	3.169
February	0.79	1.78	0.33	5.38	0.50	0.97	1.48	1.07	12.30	12.44	24.74	262,488	3.137
March	1.04	1.13	0.28	3.87	0.48	0.88	1.51	0.89	10.08	12.91	22.99	333,252	3.445
April	0.62	0.76	0.31	4.57	0.49	0.97	1.62	0.70	10.04	11.55	21.59	302,463	3.344
May	0.57	0.78	0.24	2.78	0.48	0.89	1.41	0.44	7.59	9.92	17.51	351,994	3.651
June	0.79	0.67	0.24	2.80	0.45	0.97	1.62	0.58	8.12	10.13	18.25	375,023	3.406
July	0.44	0.46	0.18	2.47	0.34	0.89	1.39	0.36	6.53	6.66	13.19	565,787	3.641
August	0.29	0.57	0.15	2.48	0.33	0.85	1.38	0.37	6.42	5.62	12.04	594,852	3.811
September	0.37	0.54	0.21	2.71	0.39	0.85	1.42	0.42	6.91	7.34	14.25	487,543	3.771
October	0.73	1.19	0.28	3.05	0.47	0.91	1.69	0.52	8.84	12.34	21.18	339,789	3.564
November	1.40	2.45	0.47	3.71	0.51	0.96	1.71	0.54	11.75	10.58	22.33	311,882	3.379
December	0.63	1.94	0.21	3.93	0.51	0.93	1.71	0.74	10.60	12.13	22.73	334,936	3.494
Avg	0.66	1.01	0.27	3.33	0.43	0.91	1.52	0.67	8.80	9.39	18.19	4,552,532	3.518

maintenance and under the further sub-headings of material and labor. The statement shows the total monthly cost as well as the cost in cents per kw-hr. for each item.

The total net output from the station is also shown as well as the pounds of coal per kw-hr. and the cost of coal per ton of 2,000 lb.

Digitized by Google

Table III is given showing the cost of maintenance of the transmission system, which includes high-tension transmission, overhead trolley, third rail and running track bonding.

In connection with the maintenance cost of overhead trolley, it should be borne in mind that the trolley construction is of

TABLE III
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
Cost of maintenance of transmission systems
Year 1910

	High tension		Overhead trolley		Third rail		Running track bonding	
	Total	Per mile	Total	Per mile	Total	Per mile	Total	Per mile
January...	$142.96	$2.04	$690.84	$35.32	$492.96	$3.74	$26.67	$1.51
February..	409.74	5.85	266.38	13.62	580.80	4.41	562.82	3.75
March.....	198.62	2.84	381.28	19.49	495.55	3.76	39.26	0.26
April.....	403.44	5.76	446.57	46.71	745.16	5.26	†30.24	0.20
May.....	256.14	3.66	291.51	30.49	1,126.40	7.95	190.05	1.27
June.....	123.21	1.76	864.62	90.44	957.42	6.75	312.08	2.08
July.....	167.90	2.40	393.62	41.17	818.29	5.77	494.79	3.30
August....	357.20	5.10	317.49	33.21	1,631.72	11.51	32.99	0.22
September.	508.51	7.26	389.73	40.77	838.87	5.92	202.05	1.35
October....	604.93	8.64	245.75	25.70	647.27	4.57	98.66	0.66
November.	171.58	2.45	363.35	38.01	1,062.98	7.50	189.83	1.26
December.	100.34	1.43	244.02	25.52	1,466.71	10.35	125.03	0.83
Total and avg. per mi. per mo....	$3,444.57	$4.10	$4,895.16	$36.70	$10,864.13	$6.46	$2,445.72	$1.36

†Credit for scrap 58.75

TABLE IV
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
Cost of operation and maintenance of substations
Year 1910

	Total for eight substations				
	Operation	Maintenance	Total	Cost per kw-hr.	Substation output kw-hr. 675 volts direct-current
January.....	$1,573.82	$373.10	$1,946.92	$0.001136	1,655,800
February.....	1,601.78	147.39	1,749.17	0.001157	1,460,200
March.....	1,618.16	174.27	1,792.43	0.001035	1,678,400
April.....	1,728.98	275.64	2,004.62	0.001251	1,554,900
May.....	1,760.46	370.91	2,131.37	0.001267	1,635,900
June.....	1,794.44	432.55	2,226.99	0.001310	1,655,600
July.....	2,006.97	317.62	2,324.59	0.001047	2,175,700
August.....	1,751.03	194.13	1,945.16	0.000811	2,349,000
September....	1,776.14	903.45	2,679.59	0.001285	2,035,200
October.....	1,744.23	145.99	1,890.22	0.001069	1,712,100
November....	1,750.62	142.23	1,892.85	0.000986	1,860,100
December.....	1,745.68	130.02	1,875.70	0.000829	2,199,400
Year.....	$20,852.31	$3,607.30	$24,459.61	$0.001082	21,972,300

Digitized by Google

rigid span type and also that current is collected by a trolley wheel on each car of a train, the number of cars per train varying from two to seven, the average being about three.

Originally the ten mile line from Newfield to Millville was equipped with overhead trolley of the same construction as the present line. This trolley was replaced by third rail the latter part of March, 1910, hence the maintenance cost per mile in Table 3 is based on 19.55 miles to March, inclusive, and on 9.55 miles from that time on.

The operation and maintenance of substations for the year 1910 is shown in Table IV. This shows the cost of operation and maintenance of the eight substations during the year 1910, by month, as well as the cost per kw. hr. output per substation and the output in direct current at 675 volts.

Detentions to Train Service

A detailed statement of the detentions to electric train service occurring during the year 1909 is given in table No. VIII. The column headed "Number of detentions," means number of trains detained and is subdivided into totals and per cent of total. The column headed, "minutes detention", shows the train minutes of detention for each cause and is subdivided into the headings of totals and per cent of totals. The column headed "car miles per minute of detention", shows the total car miles per train minute of detention for each cause.

A further subdivision of the detentions due to train equipment shown under the general heading "motive power", is given in Tables IX and X the first being for the year 1909 and the second for the year 1910. This statement shows the detentions that occurred during each year by months and it may be well to say that the figure shown above the line represents the number of detentions, while the figure below the line represents the train minutes delay for that particular detention.

Renewal of Parts of Car Equipment

The number of renewals of the various parts of car equipment for the year 1909 is given by months in Table V and the same information for the year 1910 is given in Table VI.

The car mileage for 1909 being 4,106,765 and for 1910, 4,552,056, it is seen that the number of car miles per third rail shoe replaced in 1909 was 8068 and in 1910 was 4079, giving an average of about 6005 car miles per replacement. As each car is

Digitized by Google

TABLE V

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
RENEWAL OF PARTS OF CAR EQUIPMENT
1909

Part of equipment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Third rail shoes replaced	42	38	51	42	12	10	39	59	28	71	62	55	509
Brake shoes replaced	388	237	353	423	304	435	536	592	689	476	402	462	5297
Trolley poles bent	3	1	14	8	9	12	12	15	10	10	3	11	108
Trolley poles broken	0	0	1	0	0	0	0	1	0	0	1	0	3
Trolley poles missing or replaced	0	1	0	0	0	0	0	0	0	0	4	0	5
Trolley wheels lost or replaced	24	23	25	19	27	2	36	17	38	13	11	24	259
Trolley retriever dogs broken	0	0	0	0	0	0	0	0	0	0	0	0	0
Trolley harps broken or replaced	11	7	5	2	5	3	6	6	5	1	0	0	51
800 ampere shoe fuses blown	264	198	226	193	180	113	101	125	69	138	197	279	2081
800 ampere trolley fuses blown	52	33	34	40	15	26	45	101	37	53	46	36	518
800 ampere bus fuses blown	15	10	17	9	11	6	17	14	11	21	12	59	202
25 ampere controller fuses blown	5	7	6	6	2	0	0	1	2	6	5	11	51
20 ampere No. 2 heater fuses blown	15	18	9	24	4	7	0	0	2	23	16	26	144
10 ampere No. 1 heater and comp. fuses blown	21	27	25	18	7	2	1	9	24	28	27	35	224
5 ampere cab heater fuses blown	0	1	0	0	0	0	0	0	1	0	0	4	6
4 ampere control cable fuses blown	3	4	11	1	0	1	1	2	7	1	1	2	34
2 ampere headlight fuses blown	4	0	1	3	2	0	2	3	5	1	0	13	34
1 ampere car light fuses blown	2	1	0	4	9	6	5	8	19	7	3	11	75
50 c.p. headlights burned out	20	18	10	18	11	22	40	40	36	24	16	16	271
50 c.p. headlights missing	1	1	1	3	1	4	1	0	3	1	0	1	17
16 c.p. lamps burned out	188	148	180	182	140	103	129	153	163	141	156	169	1862
16 c.p. lamps missing	41	45	42	14	42	26	15	21	33	18	28	51	376
16 c.p. lamps broken	9	18	4	18	5	22	6	7	6	9	7	14	125
Gauge lamps replaced	24	18	14	10	12	5	4	12	4	5	11	10	129

Digitized by Google

TABLE VI

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE

RENEWAL OF PARTS OF CAR EQUIPMENT

1910

Parts of equipment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Third rail shoes replaced	198	125	157	43	27	58	26	41	67	54	73	60	933
Brake shoes replaced	425	454	511	469	511	570	675	780	531	416	444	514	6300
Trolley poles bent	4	6	12	12	5	9	8	12	16	2	1	2	89
Trolley poles broken	3	3	1	3	1	0	3	0	3	1	0	0	18
Trolley poles missing or replaced	2	4	0	1	0	1	1	4	3	1	0	4	21
Trolley wheels lost or replaced	19	2	13	9	10	19	18	5	13	3	1	12	124
Trolley retriever dogs broken	0	0	0	0	0	0	0	0	0	0	0	0	0
Trolley harps broken or replaced	2	4	1	4	0	4	2	1	3	2	0	2	24
800 ampere shoe fuses blown	186	199	284	173	178	248	229	304	287	210	197	303	2798
800 ampere trolley fuses blown	56	55	51	23	22	48	107	75	70	32	17	19	575
800 ampere bus fuses blown	48	11	25	29	17	29	19	22	22	6	3	17	248
25 ampere controller fuses blown	14	8	4	6	1	2	4	0	0	1	20	5	65
20 ampere No. 2 heater fuses blown	17	13	19	7	0	2	0	0	0	2	33	13	106
10 ampere No. 1 heater and comp. fuses blown	28	31	21	19	7	9	2	1	3	5	27	25	178
5 ampere cab heater fuses blown	0	14	0	0	0	0	0	0	0	0	0	1	15
4 ampere contrl. cable fuses blown	0	0	2	0	0	1	6	5	6	2	4	3	29
2 ampere headlight fuses blown	9	24	4	6	3	2	1	1	7	5	3	17	82
1 ampere car light fuses blown	4	16	21	3	3	6	2	2	6	3	3	7	76
50 c.p. headlights burned out	25	14	3	18	16	14	21	13	18	14	12	9	177
50 c.p. headlights missing	17	21	1	3	2	3	3	2	6	0	0	6	64
16 c.p. lamps burned out	193	211	159	125	93	76	96	109	135	163	157	182	1699
16 c.p. lamps missing	72	59	64	50	49	45	25	26	27	39	54	67	577
16 c.p. lamps broken	19	20	7	6	0	2	5	4	9	5	3	3	83
Gauge lamps replaced	27	17	6	13	9	8	10	8	7	1	24	0	110

Digitized by Google

equipped with four shoes this gives an average life of 24,020 miles per shoe.

Likewise the number of car miles per brake shoe was 775 in 1909 and 722 in 1910 or an average of about 747 car miles per replacement. The average life of each brake shoe is therefore about 5976 miles.

The number of replacements of the remaining items is governed rather by special occurrences than by mileage, with the exception of the lamps, the average life of which is not readily obtainable owing to incomplete data concerning number of hours burned.

A statement is also included showing the breakage of gears and pinions by month for the years 1909 and 1910. This will be found by reference to Table VII.

TABLE VII

WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE

Gear and pinion breakages

	1909	1910
January	4	1
February	3	1
March	5	3
April	2	1
May	1	5
June	0	1
July	0	0
August	1	0
September	1	0
October	2	0
November	0	0
December	2	1
Total	21	13

Table XI shows, by months, for the years 1907, 1908, 1909 and 1910 certain general power data, which are included as being of some interest. This statement, shows the kw-hr. output from power station, the cost in mills per kw-hr. output, pounds of coal per kw-hr., and the efficiency of transmission and conversion from the alternating current bus in the power station to direct current bus in substations.

An improvement will be noted in the reduction of cost of power, as well as a reduction in coal consumption per kilowatt hour. The most marked improvement, however, will be noted in efficiency of transmission and conversion, which is accounted for by the fact that the operation of the substations is followed up with care so as to minimize the idle operation of rotaries.

Digitized by Google

TABLE VIII
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
Detentions
Year 1909

Causes	Train detentions, number, time and per cent for various causes				
	Number of detentions		Minutes detention		
	Total	Per cent of total	Total	Per cent of total	Car miles per minute detention
Transportation.					
Boat connection	51	0.553	180	0.403	22,815.36
Baggage, express and mail	1898	20.575	8373	18.749	490.47
Heavy travel	1232	13.355	4612	10.328	890.45
Collecting tickets	72	0.781	334	0.748	12,295.70
Train connections	977	10.591	5517	12.354	744.38
Traffic ahead	1723	18.677	7842	17.561	523.68
Held at signal	1390	15.068	4767	10.675	861.50
Stops on order	73	0.791	165	0.369	24,889.49
Fast schedule	34	0.368	57	0.128	72,048.50
Picking up and cutting off cars	411	4.455	1312	2.938	3,130.15
Fog	41	0.444	127	0.284	32,336.73
Signal failure	208	2.255	860	1.926	4,775.31
Accidents	26	0.282	261	0.584	15,734.73
Obstructions	33	0.358	194	0.434	21,168.89
Miscellaneous	283	3.068	1427	3.196	2,877.90
Total transportation	4852	91.621	36028	80.677	113.98
Motive power.					
Power house trouble	15	0.163	69	0.155	59,518.30
High tension line trouble	14	0.152	81	0.181	50,700.80
Lightning	12	0.130	47	0.105	87,377.90
Overloads in substations	11	0.119	61	0.137	67,324.00
Third rail shorts	3	0.032	14	0.031	293,340.40
Third rail out of place	1	0.011	8	0.019	513,345.13
Third rail anchor on fire	1	0.011	5	0.011	821,353.00
Third rail protection out of place	1	0.011	1	0.002	4,106,765.00
Trolley wire trouble	253	2.742	1920	4.299	2,138.94
Train equipment	237	2.569	1568	3.511	2,619.11
Total motive power	548	5.940	3774	8.451	1,088.17
Weather Conditions.					
Snow, head winds, wet rail	178	1.929	4043	9.054	1,015.77
Sleet on third rail	47	0.510	812	1.818	5,057.59
Total weather condition	225	2.439	4855	10.872	845.88
Grand total	9225	100.00	44657	100.00	91.96

Total car mileage	4,106,765
Car miles per detention	445.18
Car miles per minute of detention	91.96

Digitized by Google

TABLE XI
WEST JERSEY & SEASHORE RAILROAD ELECTRIC TRAIN SERVICE
General power data

	1907				1908			
	Alternating Current kw-hr Power Station Output	Cost in Mills per Kw-hr. Output	Lb. of Coal Kw-hr. Output	Efficiency Power Sta. Bus to Substation Bus	Alternating Current Kw-hr. Power Station Output	Cost in Mills per Kw-hr. Output	Lb. of Coal Kw-hr. Output	Efficiency Power Sta. Bus to Substation Bus
January	1,911,600	8.83	3.91	72.6	2,009,600	6.10	3.49	73.3
February	1,691,500	7.95	3.63	74.5	1,913,100	6.35	3.55	73.6
March	1,583,000	7.76	3.96	71.5	1,873,300	6.17	3.46	72.3
April	1,464,300	7.43	3.95	74.0	1,836,200	5.86	3.45	71.8
May	1,400,400	6.81	3.53	72.1	1,744,900	6.06	3.40	69.6
June	1,395,700	7.65	3.98	70.6	1,707,500	5.91	3.52	74.8
July	1,938,100	6.05	3.65	71.6	2,104,300	5.43	3.37	75.6
August	2,082,000	6.00	3.43	71.6	2,268,000	5.43	3.18	75.8
September	1,855,300	6.07	3.46	71.7	1,849,200	5.76	3.18	74.7
October	1,849,800	5.99	3.53	82.8	1,786,700	5.78	3.25	72.8
November	1,893,600	5.86	3.51	71.3	1,802,000	5.78	3.35	74.7
December	2,053,600	6.00	3.51	72.5	1,993,000	5.80	3.25	76.2
Av. for year	1,759,900	6.80	3.67	72.2	1,907,300	5.92	3.37	73.8
	1909				1910			
January	1,959,700	5.67	3.23	76.1	2,131,000	5.15	3.31	81.8
February	1,756,500	5.71	3.25	76.1	1,865,300	5.73	3.46	82.4
March	1,903,600	6.04	3.33	76.1	2,168,600	5.42	3.27	81.3
April	1,869,300	5.90	3.27	75.0	2,031,400	5.62	3.22	80.1
May	1,788,800	5.65	3.26	75.5	2,115,900	5.25	3.27	79.5
June	1,749,200	5.77	3.22	77.7	2,167,500	5.68	3.14	80.3
July	2,426,000	5.21	3.25	78.0	2,784,300	5.88	3.16	82.5
August	2,324,400	5.27	3.34	81.5	3,088,300	5.11	3.06	80.7
September	2,056,100	5.28	3.34	80.3	2,590,400	5.17	3.31	82.9
October	1,836,600	5.40	3.27	80.1	2,229,000	5.48	3.17	80.8
November	1,869,500	5.49	3.41	80.7	2,381,500	5.19	3.29	81.9
December	2,154,800	5.42	3.41	81.0	2,759,300	5.31	3.35	83.4
Av. for year	1,962,600	5.55	3.30	78.4	2,359,400	5.42	3.25	81.6

Digitized by Google

FOR YEAR 1909

Trolley			Headlight		Hot Bea	
Wheels defective	Ropes broken	Retriever	Fuse blown	Burnt out	Armature	Motor axle	Journal
..	..	..	..	2	..	..	..
..	..	..	..	9	..	..	..
..	..	..	..	2	..	..	..
..	..	..	..	8	..	..	..
..	1	2	..	1	..	..	1
..	6	3	..	3	..	..	36
..	..	..	..	..	..	..	3
..	..	..	..	..	..	..	35
1	..	..	..	..	..	..	2
1	..	..	..	..	..	..	12
..	..	1	..	5	..	..	2
..	..	3	..	13	..	..	19
..	..	..	..	5	..	..	3
..	..	..	..	23	..	..	26
..	..	..	..	4	..	2	2
..	..	..	..	16	..	8	24
..	1	..	1	9	..	2	4
..	3	..	1	56	..	5	82
..	..	1	..	2	..	..	4
..	..	4	..	7	..	..	61
..	1	..	..	1	..	..	2
..	2	..	..	3	..	..	13
..	1	1	2	3	..	..	1
..	1	3	18	21	..	..	10
1	4	5	3	34	..	4	24
1	12	13	19	159	..	13	318

Digitized by Google

ANY

RAIN

D

Emergency attachment

Trolley poles defective

Janu

Febr

Marc

Apri

May

June

July

Aug

Sept

Oct

Nov

Digitized by Google

ANY

RAIN EQUIPMENT FOR YEAR 1910

Date	Trolley							Headlight	Hot Bea		
	Emergency attachment	Trolley poles defective	Poles lost	Wheels defective	Ropes broken	Retriever	Fuse blown	Burnt out	Armature	Motor axle	Journal
January	..	..	1	2	1	1	..	5	..	1	..
	..	..	4	9	2	2	..	37	..	1	..
February	..	..	..	..	2	1	2	2	..	..	1
	..	..	..	..	10	6	9	5	..	..	1
March	..	6	..	..	..	..	..	2	..	1	1
	..	19	..	..	..	..	..	15	..	10	19
April	..	..	..	..	..	..	..	3	..	..	1
	..	..	..	..	..	..	..	6	..	..	2
May	..	..	..	..	..	..	..	2	..	..	1
	..	..	..	..	..	..	..	4	..	..	1
June	..	..	..	..	1	..	..	2	..	1	1
	..	..	..	..	9	..	..	8	..	2	1
July	..	..	..	..	3	..	..	3	..	1	1
	..	..	..	..	13	..	..	9	..	5	1
August	..	..	..	..	2	1	1	5	..	1	1
	..	..	..	..	7	12	2	20	..	3	6
September	..	..	..	..	1	..	1	2	..	1	1
	..	..	..	..	4	..	6	3	..	12	5
October	..	..	..	..	..	..	..	..	1	..	1
	..	..	..	..	..	..	..	..	3	..	1
November	..	..	..	..	1	..	..	3	..	..	1
	..	..	..	..	3	..	..	9	..	..	1
December	..	..	1	..	..	..	4	10	..	1	
	..	..	2	..	..	..	18	40	..	2	1
Year	..	6	2	2	12	3	8	39	1	7	3
	..	19	6	9	48	20	35	156	3	35	43

Digitized by Google

Digitized by Google

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 29, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

TRANSMISSION SYSTEM OF THE CENTRAL COLORADO POWER CO.

BY P. T. HANSCOM

1. The transformers at the Glenwood power house and at all substations are delta connected. The transformers at the Boulder power house are Y connected on account of better voltage ratio, and are operated with ungrounded neutral.

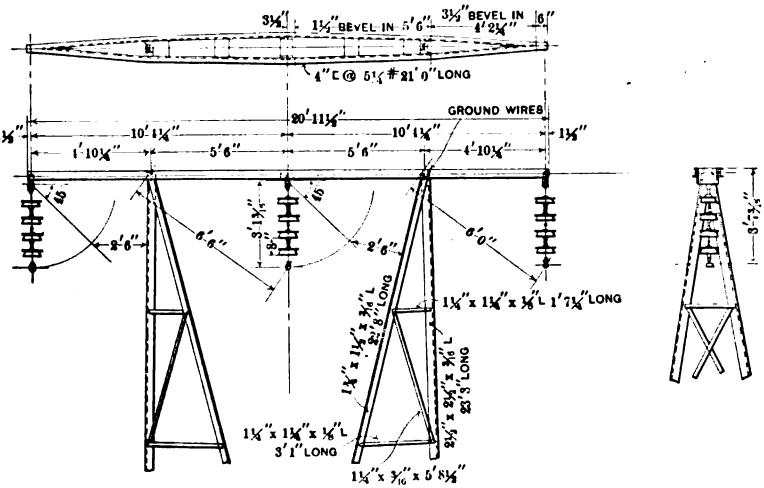


FIG. 1.

2. Two ground wires are used throughout on the Boulder line and for a distance of five miles from any station on the Glenwood line also between Leadville and Dillon and across the Argentine and Haggerman Passes. The wires are grounded at each tower and spaced as shown in Fig. 1.

3. The standard span is 660 ft. and the average throughout the lines 750 ft.

The conductors on the Glenwood line are No. 0 B. & S. copper, composed of six strands with a hemp center, except

Digitized by Google

between Leadville and Dillon where the conductors are No. 1 copper. The Boulder line is also No. 1 copper.

The conductors are drawn to an elastic limit of 35,000 lb. per sq. in. and ultimate strength of 60,000 lb. per sq. in.

There are a number of spans between 1,500 ft. and 2,000 ft. and one span of about 2,900 ft. with standard copper conductors.

At some of the railroad crossings and in a few spans, exposed to severe winds, ½-in. high-strength stranded steel cable is used for conductors.

4. The records of the operating department show 10 interruptions from lightning during the season of 1910 from 63 recorded lightning storms on the high-tension lines.

The records of the operating department are as follows:

CENTRAL COLORADO POWER COMPANY

Record of lightning storms, June 1 to November 1, 1910

June 13. In the afternoon lightning storms was general over all Central Colorado Power Company's lines; no disturbance on Company's system during the day.

June 14. Lightning and rain east of Argentine Pass; high winds between Leadville and Dillon. Lightning lasted about six hours. A disturbance interrupted Dillon and Denver service once. On patrol next day broken insulator discs were found at the following towers near Leadville: Nos. 372, 378, 381 and 435. These were repaired later during a prearranged shut down, service being maintained over them in the meantime. The transmission line was not dead during the day.

June 15. From 8:00 to 9:00 p.m. heavy lightning storm on Argentine Pass. One disturbance caused by a discharge to tower 752 from the clips of the disconnecting switch. This arc caused a shut down on the transmission line of 3 min., being the only disturbance experienced during the storm.

June 16. Lightning and snow on Argentine Pass. No disturbance on line.

June 17. Lightning and rain on Argentine Pass. No disturbance on line.

June 18. Lightning and rain on Argentine Pass, at Idaho Springs and around Boulder. Generally stormy along Eastern Slope. No disturbance on system.

June 20. Lightning and rain on west side of Argentine Pass, between Dillon and Leadville and west of Hagerman Pass. No disturbance on transmission line. One slight disturbance on 13,000-volt feeder out of Dillon substation. One discharge on 13,000-volt circuit in the Boulder district about 5 p.m. interrupting one customer.

June 21. Severe lightning around Barker and other parts of Boulder district. No disturbance on line.

Digitized by Google

June 22. Lightning around Golden and Idaho Springs. No disturbance on system.

June 23. Cloudy, with lightning around Boulder. No disturbance on system.

June 24. Severe lightning between Denver and Boulder. No disturbance on system.

June 27. Lightning around Denver, Golden and Boulder, also Idaho Springs. One disturbance which caused Denver Gas & Electric Company's switch in its West Side station to open, but did not affect service to Northern Colorado Power Co., or any other customer.

June 28. Severe lightning around Boulder and Dillon all the afternoon up to 9 p.m. No disturbance on transmission system. One 13,000-volt feeder circuit out of Boulder and one 13,000-volt circuit out of Dillon substation were interrupted.

June 29. Lightning in Boulder district from 4.00 to 8.00 p.m. One disturbance on transmission line, caused by trouble originating on a 13,000-volt feeder out of Boulder. This did not affect service over the transmission line, but the Denver Gas & Electric Company's switch opened, separating the system.

June 30. Generally cloudy and stormy. Severe lightning around Boulder in the afternoon. No disturbance on transmission system. One disturbance on a 13,000-volt feeder from Boulder.

July 1. Lightning severe around Idaho Springs; some lightning around Denver in the afternoon. No disturbance on system.

July 3. Storm around Dillon from 6.30 to 9 p.m. One disturbance on line but not affecting delivery to substations. Denver Gas & Electric Company tripped off of their end of the feeder. One disturbance on a 13,000-volt circuit out of Dillon substation.

July 11. Lightning around Idaho Springs about 7.00 p.m. No disturbance on ystem.

July 12. Severe lightning around Denver. No disturbance on Central Company's system.

July 16. Severe lightning storm on Argentine Pass and at Idaho Springs. No disturbance on system.

July 17. Generally cloudy with some lightning. No disturbance on system

July 18. Generally cloudy with lightning over almost the entire line system. One disturbance due to the discharge which was observed to strike between towers 938 and 939. Transmission line was not dead, but regulation was poor for one-half min. The Denver Gas & Electric Company's switch tripped out on this occurrence and they were separated from Central Company's service for 15 min.

July 19. Severe lightning around Georgetown; cloudy over transmission line. Lightning broke insulators at towers 431, 437 and 604, all between Dillon and Leadville, causing two interruptions. After the first one service was resumed, but after the second one the broken insulators prevented recharge of the line until they were replaced.

Digitized by Google

July 20. Lightning storm general during the afternoon. One discharge observed to hit ground wires on towers 885 and 886 but no customers were interrupted except Denver Gas & Electric Company, whose switch opened automatically, operating the systems for 7 min., Leadville and Dillon substation instruments showing continuity of service and no disturbance.

July 21. General lightning storm in the afternoon. One disturbance on the 13,000-volt feeder out of Boulder which caused slight fluctuation on transmission line, but not affecting delivery to substations. During this disturbance the Denver Gas switch opened automatically, separating the systems for 6½ min.

July 27. Lightning around Dillon, Argentine and Leadville all day, around Shoshone and Boulder in the afternoon. One disturbance on transmission line caused momentary variation and separated Denver Gas from Central Company's system for about 6 min. Voltage low on transmission line for about 20 sec. During this storm other parts of the State were seriously affected.

July 28. Lightning around Dillon and Boulder in the morning. During the afternoon very heavy rain with severe lightning was general over the whole state. One roof bushing at Boulder was damaged but was automatically disconnected without interrupting service in Leadville, Dillon or Denver substations. The automatic switch in the Denver Gas Company's station opened, separating the system for 6 min. Four other slight disturbances, the first of which was caused by lightning breaking insulators at tower 389 near Leadville, the other three being caused by the remaining insulators furnishing insufficient insulation, which broke down at intervals until the line was disconnected by prearrangement to replace the damaged insulators. The Colorado Telephone Company's service was seriously interferred with, both locally and on the toll lines. A great deal of cable on their Denver circuits was damaged, and it was reported that about 600 telephones in Denver were out of service.

July 29. Heavy rains all day over the entire system. Lightning general. One disturbance; insulators on middle conductor at tower 1008½ damaged.

July 30. After 11.00 a.m. lightning was general around Barber, Dillon, Leadville and on the western slope. One disturbance at 2.00 p.m. Transmission line not dead.

July 31. Rain and lightning between Argentine Pass and Hagerman Pass. No disturbance.

Aug. 1. About noon small local storm just west of Denver caused no disturbances on Central Company's system.

Aug. 2. During the afternoon from 2.00 p.m. to 6.00 p.m. there was some lightning and slight showers along the transmission line. No disturbance.

Aug. 3. Partly cloudy during the day. No rain. Small lightning discharges in the afternoon. No disturbances.

Digitized by Google

Aug. 4. Weather Cloudy. Showers in the afternoon. Lightning general over whole line. One severe discharge at 1.28 p.m. Destroyed a roof bushing at the Denver substation and interrupted service to Denver and Boulder 17 min. No interruption at Dillon or Leadville. Heavy rains at Boulder in the afternoon, accompanied by severe lightning. Caused two disturbances on the 13,000-volt distribution line without disturbing the transmission system.

Aug. 5. Wind, rain and lightning in the afternoon generally. No disturbance on transmission system.

Aug. 6. Lightning in afternoon ast of Leadville, north of Dillon and around Idaho Springs. No disturbance on transmission system.

Aug. 7. Rain near Idaho Springs. Lightning in the afternoon west of Leadville and on Argentine Pass. No disturbances on transmission system.

Aug. 8. Wind and rain storm from Idaho Springs to Denver in the afternoon, with some lightning. Very heavy lightning storm at Denver, in the evening lasting about three hours. No disturbance.

Aug. 10. Partly cloudy. Storm around Idaho Springs and Boulder in the afternoon with rain at Boulder and some lightning. No disturbance.

Aug. 12. Weather cloudy. Rain and lightning between Leadville and Shoshone all day. Rain and lightning in Denver in the evening. No lightning disturbances on transmission system. Broken conductor between towers 126–127. Break caused by bullet from rifle.

Aug. 13. General storm with rain from Argentine east. No disturbance on transmission system.

Aug. 14. Severe lightning and rain at Idaho Springs from 5 to 6 p.m. One disturbance caused a discharge across a transformer bushing at the Dillon substation.

Aug. 15. Rain west of Dillon with some lightning. No disturbance on transmission line.

Aug. 16. Lightning around Idaho Springs beginning at 1.30 p.m. Lightning around Boulder at about 3 p.m. Insulators punctured on tower 472 caused shutdown transmission from Leadville east.

Aug. 20. Westher cloudy over whole system. Rain and lightning at Waldorf in the afternoon.

Aug. 22. Weather cloudy and stormy. Lightning around Idaho Springs east of Denver. No disturbance.

Aug. 23. Stormy and rain from Shoshone to Leadville in the afternoon. Lightning from Shoshone to Argentine. One discharge near Shoshone caused the horn gap outside of Shoshone station to break down, shutting down Dillon and Leadville and causing the Denver Gas Company's switch to trip. The attendant at the Denver substation disconnected the Shoshone line quickly enough to prevent an interruption to the Boulder

Digitized by Google

customers, and load continued to be carried by the Boulder Plant. Service to Denver substation from Boulder was thus momentarily interrupted.

Aug. 24. Lightning around Denver in the afternoon. No disturbance on transmission line.

Sept. 1. Lightning storm in the evening from Basalt to Dillon, from Idaho Springs to Denver and Boulder. No disturbance on transmission system. One disturbance on a 13,000-volt line from Boulder.

Sept. 2. Lightning in the evening along line from Dillon to Denver. No disturbance.

Sept. 11. Lightning around Denver in the afternoon. No disturbance on system.

Sept. 13. Heavy lightning storm all along transmission line in afternoon. No disturbance on Central Company's system.

Sept. 14. Some lightning along transmission line in the evening. No disturbance.

Sept. 15. Lightning around Idaho Springs in the afternoon. No disturbance.

Sept. 18. Severe lightning in afternoon and evening. Four disturbances on transmission system. One of these disturbances interrupted service.

Sept. 19. Severe lightning storm during early evening. No disturbances.

Sept. 20. Severe lightning storm with rain east of Argentine Pass. No disturbance.

Sept. 21. Severe lightning storm in afternoon around Denver over Boulder and Shoshone. No disturbance.

Sept. 22. Severe lightning storm in the afternoon broke insulator on tower 919. Interrupted no customers except Denver and Idaho Springs.

Sept. 25. Very severe lightning storm over Denver in the afternoon. No disturbance.

Oct. 14. Severe lightning storm in the afternoon and evening from Dillon west to Georgetown and north to Boulder. No disturbance on high-tension transmission system. One interruption of all distribution lines from Boulder; three additional interruptions on one distribution circuit from Boulder with additional interruption on each of two other distribution circuits from Boulder.

Oct. 15. Some lightning on Argentine Pass in the afternoon. No disturbance.

Oct. 16. Some lightning on Argentine Pass in the afternoon. No disturbance.

NOTE.— 10 interruptions due to lightning on high tension lines.
63 recorded storms.
135 days.

5. Information on charging current is given in the January, 1911, issue of the Institute PROCEEDINGS. See papers by Faccioli and Ryan.

Digitized by Google

6. No electrical difficulties have occurred chargeable to insulators and mechanical difficulties of insulators have been limited to two or three defective connecting links between units. The normal strength of links is equal to the No. 0 conductor.

Some difficulties have been experienced from lack of stability of conductors in the more exposed sections of the line due to low horizontal stress and low vertical component at point of support. Such difficulties have occurred in local sections exposed to the more violent winds.

In some of the spans on the eastern slope where the line crosses the opening of canons, the wind at times comes whirling out of the canon at excessive velocity, intersecting other currents of air which produce wind eddies with the effect of lifting the entire span, shaking the conductors violently and mixing them up generally. To meet such conditions it has been necessary to dead end the spans, increasing the horizontal stress, and in one span it has been found desirable to increase the spacing of conductors.

7. No difficulties have been experienced from high-tension switches or operation of same with and without load. High-tension switches of the oil break type are installed at all substations, but none are installed at either of the two power stations.

8. Under present operating conditions the power factor at all power stations is about unity, hence no attempt has been made to control the charging current of the line.

The system is operated in multiple with the following power stations:

Leadville Light & Power Co. (steam).
United Hydro Electric Co. (hydraulic).
Denver Gas & Electric Co. (steam).
Northern Colorado Power Co. (steam).

There are two 5000-kw. generators installed in the Glenwood power house and two generators of the same capacity are installed at the Boulder power house. The combined water wheel capacity at both plants is 39,000 h.p. The available generator capacity for continuous service is considerably in excess of the generator ratings given above.

9. Some difficulty was experienced with high tension bushings and terminals during the first few months of operation, but these difficulties have been practically eliminated by changes in design and method of supports.

Digitized by Google

10. Aluminum cell lightning arresters are installed at Dillon, Denver and Boulder and their performance has been satisfactory. No difficulty has been experienced with the arresters.

11. Experience with wind conditions is given above. During spring and fall months sleet and snow has collected on wires at the lower elevations, and in one instance before the line was placed in commission the accumulation of sleet and snow on a No. 0 conductor was found to be 1.9 lb. per linear foot.

12. Data on corona is given in the January issue of the Institute PROCEEDINGS.

13. The telephone communication may be considered good as there is no disturbance or interference under normal operating conditions.

14. The voltage regulation at the Denver substation under normal operating conditions is within 1 per cent of a given value and the departure from this value for different periods of the day is about 3 per cent.

15. The towers are angle construction for horizontal circuit.

Digitized by Google

DISCUSSION ON "DESIGN, CONSTRUCTION AND TESTS OF AN ARTIFICIAL TRANSMISSION LINE", "PROTECTION OF ELECTRICAL TRANSMISSION LINES", "TESTS OF GROUNDED PHASE PROTECTOR ON THE 40,000-VOLT SYSTEM OF THE SOUTHERN POWER CO.," "TESTS OF LOSSES ON HIGH TENSION LINES." SCHENECTADY, FEBRUARY 14, 1911. (SEE PROCEEDINGS FOR JANUARY AND MARCH, 1911.)

(Subject to final revision for the Transactions.)

Ralph D. Mershon: There are one or two questions I would like to ask. One is with reference to the method of measurement of the line voltage which assumed the constancy of the ratio of the step-up power transformer. I wonder how accurate it was. A small error in voltage in some of the measurements would make a considerable amount of difference in the loss curves, and there is a chance for distortion of wave, other modifications of voltage, due to reactions in the transformer, producing a change of ratio.

Another statement appears which raises a somewhat similar question as to the wave form impressed on the line, and the possibility there was for distortion. This, of course, is a question similar to the previous one in regard to measurement. In the case of Fig. 4, it would be interesting to know where the charging current to the line was measured. I do not see that there is any statement made as to whether it was made on the low voltage side of the transformer or in the line itself. The average atmospheric conditions of the tests of curve *B* Fig. 4 of the other curves are given. It would have been an addition to the paper, I think, if the individual readings for some of the points on the curves were given. Additional information bearing on this matter has been given me by Mr. Faccioli as applied to Fig. 9. He says that the vapor product applying to that curve varied from 0.11 to 0.274. It is brought out in my Niagara paper that for low value of vapor product the variation in the losses with vapor product are not considerable, not such as would ordinarily attract attention, and it was because of that, I think, that I did not notice them at all in my Telluride measurements. It is only when you get above these values, as I remember it in the neighborhood of 0.3 and 0.4, that the effect of the moisture in the atmosphere becomes marked.

This low value of the vapor product might or might not account for lack of variation in visible corona with variation of atmospheric conditions. It would seem from the tests made so far by Mr. Faccioli that possibly the visible corona is not affected by humidity conditions but as I think I have said once or twice before, the critical point as I define it, is not the point at which corona begins, but at which the loss curve turns sharply upward.

Mr. Faccioli has determined that according to my Niagara data, the critical voltage of the Denver-Boulder line, should be 88.5 kilovolts. Unfortunately, Fig. 9 has not a sufficient amount of the lower part of the curve for the accurate application

Digitized by Google

of my method. But my estimate for that curve, such as there is of it, is that by my method the critical voltage would be about 87 kilovolts, which is not so far out from the value Mr. Faccioli obtains. The curve of Fig. 9 is the result of differences of two sets of measurements. The subtraction method may lead to errors of considerable magnitude especially in the lower part of the curve, resulting in considerable variation in the curve one way or the other. I think it hardly fair, therefore, to give this curve much weight in any critical discussion of either my method of obtaining the critical point or my results.

There is another question I would ask in regard to where the wattmeter was used with the coil directly in the high voltage circuit. What was the possibility of electrostatic effects affecting its reading?

The method of analysis Mr. Faccioli has adopted for determining the critical point does not appeal to me much. You first get a set of observations in which there is more or less error. You draw in the most probable curve. Then you get an empiric formula for the top part of the curve as closely as you can; more or less error there. Then by means of this formula you extend the upper limb of the curve down to the voltage axis, find the intersection and call that the critical point. It seems to me my method is much quicker, safer and much more rational especially as I do not agree in the use of the square law for the upper part of the curve. Although the square law may appear to apply, it seems to me there is every reason why it actually should not apply. For, if we are dealing with a sine wave voltage the loss above the critical point should be some function of that part of the area of the wave included between the two values of critical voltage. Therefore this loss cannot, rationally, follow the simple law of squares. As a matter of fact, if you derive the expression for the effective voltage of that part of the sine wave included between the two values of critical voltage, assume it to be acting against the critical and through a resistance and derive a curve connecting total impressed voltage and loss, you get a curve which has a shape closely approximating that of the actual loss curves obtained.

Mr. Faccioli says: " The law which gives the critical voltage at which corona appears in function of the diameter of the conductors and the distance between conductors is $V = M\, r \log D/r$, where M is a constant depending upon the barometric pressure and temperature, D is the distance between the centers of the conductors, r the radius of the conductor." I thought that expression was the expression giving the rate of fall of potential at the surface of the conductor, and that Professor Ryan had demonstrated pretty thoroughly that that was not the law which governed the beginning of corona, and that that is the reason why these curves do not follow the theoretical law as pointed out by Mr. Faccioli. They do, however, follow the empirical formula which I gave in my paper which is not, however, independent of diameter.

Digitized by Google

This question of the vapor product and its effect is something I have been looking for very interestedly in the further measurements of others. So far no one else seems to have gotten it. Referring to Mr. Creighton's paper, I hope that Mr. L. C. Nicholson who is here will tell us about work he has been doing independently along the same lines, and some of the results he has obtained.

Charles S. Ruffner: The measured losses referred to in the paper occur when the receiving end of the line is open circuited, and are greatly reduced when the load is delivered, or even when unloaded substation transformers are connected. That these losses are not serious in service is shown by the meter readings for the year. During 1910 88.2 per cent of the number of kilowatt hours generated was delivered to the low tension side of the substation transformers; that is, 11.8 per cent of the energy generated was used in station auxiliaries or lost in step-up transformers, transmission line and substation transformers. It is probable that less than 6/10 of this total loss should be charged to the line, so that the loss, in line only, amounts to about 7 per cent of the energy generated.

On account of the difficulty of measuring the potential at the receiving end of the line at open circuit, the effective value and wave form of the voltage is unknown under these conditions, but it is probable that the effective voltage is 25 per cent higher than at the generating station. It is also probable that in the section of line farthest from the generating station the distortion of the voltage wave may greatly increase the losses during part of the cycle above the loss that would correspond to the same effective voltage with a sine wave. At least it is possible that over some intermediate section of the line where the effective value of the voltage is insufficient to produce excessive loss, there may still be parts of the distorted voltage wave sufficiently above this critical voltage to cause excessive losses during part of the cycle. This would give greater losses at any measured effective voltage than those calculated for sine waves.

An interesting point that cannot be determined from the data at hand is suggested by the distortion of the wave of charging current, which, under some conditions, may approximate triple frequency. This may have an appreciable effect on such losses as are connected with inductive effects. That is to say, there may be a question whether the calculated ohmic losses, which have been subtracted from the measured total open circuit loss, should not be modified because of the change in current distribution in the circuit caused by this higher frequency current. If there is any such effect, the resulting values of " corona and insulator losses " given by such subtraction might include other losses. However, the fact that the greatest losses occur in the parts of the line farthest from the generating station shows that the loss is almost altogether a function of the voltage.

It is unfortunate that there is not available an oscillogram of

Digitized by Google

the voltage wave at the open end of the line when no transformers are connected. The importance of this is evident when, under normal voltages at Shoshone, the power required for the total line is about 2,300 kw. at open circuit and is reduced to about 1,300 kw. by connecting unloaded transformers to the line at Denver and at Boulder.

L. C. Nicholson: Professor Creighton mentions three foes to the continuity of service on a long distance transmission line; first, direct lightning stroke shattering insulators, second, induced effects from nearby lightning which may cause insulators to flashover, and third, outside interference. Mr. Mershon promises an insulator which will relish the direct stroke, and Professor Creighton tells us how to get rid of flashovers on one wire at a time so as to obviate consequent damage to insulators and conductors. No one is bold enough to suggest a cure for outside interference.

Professor Creighton explains why flashovers should occur on only one wire at a time. However, flashovers do not occur always as they should, and frequently involve two and sometimes three phases simultaneously. Our experience with these matters indicates that 60 per cent of all lightning disturbances are two-wire short circuits, that is, two insulators on different phases are over simultaneously, 30 per cent are single insulator flashovers, that is, from one wire to ground, and 10 per cent are three-phase short circuits caused by simultaneous flashing of insulators on all three phases. Experience further indicates that the single-insulator flashovers involving limited current, usually go out after a few seconds, and do no considerable damage. Hence an arc suppressor to be of maximum benefit should provide for suppressing phase to phase arcs as well as phase to ground arcs.

Apparatus is in operation on the lines of the Niagara, Lockport & Ontario Power Co., to extinguish arcs occurring from line to ground and between phases and to accomplish this result in so short a time that synchronous receiving apparatus remains in step and thus avoid shutdowns. This apparatus consists essentially of enclosed fuses connected to the lines by means of quick acting air switches actuated by excess current in the line wires. The fuses act to shunt the primary short circuit on the lines and thus extinguish the arc. The switches are selective and short circuit by fuses the phase or phases which are already short circuited by the flashover arc or arcs. The fuses consist of No. 14 B. & S. copper wire contained in a paper tube 6 ft. long. The entire operation of throwing the fuses on the circuit and burning them out consumes less than 1/5 of a second. This short time is too small to throw heavily loaded synchronous motors or rotary convertors out of step. In fact the disturbance to the system is barely noticeable. Single-phase oil switches have been tried for this purpose, but we found them too slow to close and in great danger of exploding when opening heavy short circuit current, which amounts to 2,000 amperes or more.

Digitized by Google

Taylor Reed: In the papers which have been presented this evening there has been quite a wide application of the oscillograph in the observations made, ranging all the way from comparatively laboratory conditions in Professor Cunningham's paper to quite trying, what you may call road conditions, in Mr. Faccioli's paper. I would like to speak more particularly with reference to the oscillograph observations in Mr. Faccioli's paper. The oscillograph is usually considered quite a delicate instrument, but I think it is used under conditions there which quite demonstrate its practicability. The particular instrument in use was not a new one by any means, it had seen some pretty severe service under factory conditions. It was taken out to quite a number of remote points, where the matter of accident was serious, and where the matter of repairs was very formidable. Where appliances were very meagre it was shipped about a number of times, half a dozen or more, from one point to another. It was used under all sorts of crude conditions and the films were developed under such circumstances and with such appliances as could be got together at the various points of observation. Further in some of the observations it was necessary, as I understand, to relay the signals for the switch operation through two or three persons at the observing end, through more than a hundred miles of private telephone line, and through two or three persons at the switch end, and yet the observations were obtained with an exposure of the film of only a very few seconds, two or three or four seconds. I may say that the instrument as sent out was not in all particulars adapted to the purpose—the observer put on it, with such appliances as he had available, the necessary additional apparatus, to use very much longer films than had been provided, etc., showing a capability and resourcefulness of the oscillograph operator in the matter of taking observations, of which we have had altogether too little. The oscillograph in its development was brought into actual practical use by practical necessities rather than for academic purposes, but when it was prepared, however, and offered for use, it was taken up and adopted more immediately in academic quarters than in practical operating quarters, after which followed its adoption quite extensively for more practical operating purposes, and it is now distributed fairly widely for these purposes. I am sorry to say that I think a good many of the pieces of apparatus turned out for academic purposes have gone into glass cases and for the most part reposed there for show purposes, and I think that those which have been applied to operating conditions have been much more satisfactorily used.

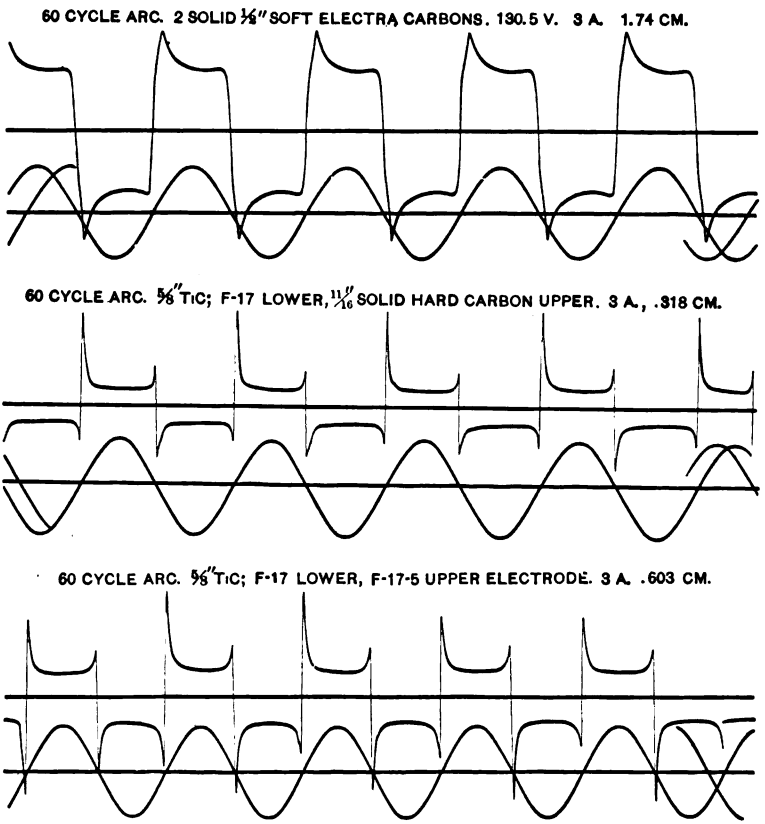
J. L. R. Hayden: In the latter part of Professor Creighton's paper two important and little understood phenomena are discussed, the time lag of the dielectric spark and the time lag of the arc.

The industrial importance of the dielectric spark lag is obvious when seeing the enormous transient voltages which are re-

Digitized by Google

quired to break down even a short gap. Still less is known on the time lag of the arc. We have very complete data on the electrical characteristics of the arc under stationary conditions, largely from the work of Dr. Steinmetz, but very little on the transient phenomena of the arc.

Some years ago when developing the mercury arc rectifier we tried to find the time lag of the formation of the mercury arc by studying the time of overlap required for stability.


60 CYCLE ARC. 2 SOLID ½" SOFT ELECTRA CARBONS. 130.5 V. 3 A. 1.74 CM.
60 CYCLE ARC. ⅝" TIC; F-17 LOWER, 11/16" SOLID HARD CARBON UPPER. 3 A., .318 CM.
60 CYCLE ARC. ⅝" TIC; F-17 LOWER, F-17-5 UPPER ELECTRODE. 3 A. .603 CM.

In the mercury arc rectifier during every half wave the arc is formed by the dying out arc of the preceding half waves. By inductance the arcs are overlapped so as to maintain each arc until the next one is formed. By gradually reducing the inductance we tried to find the minimum overlap of the arc and from that the time required to start the arc. With currents of from 1 to 2 amperes and about 20 cm. arc length, this time was about one-thousandth of a second, but very much shorter with

Digitized by Google

larger currents and shorter arcs. We found that even minute traces of residual gases in the vacuum greatly retarded the formation of the arc so that the above values can be considered only as the upper limit of time.

Recently we have tried to investigate the same phenomenon by studying alternating arcs by oscillograph.

In stationary conditions maximum current gives minimum voltage in the arc.

Oscillograms of alternating arcs show the minimum voltage to take place later than the maximum current, and from this further investigation may give some data on the time lag of the arc.

The three oscillograms show this effect for an arc between soft carbons, an arc between two terminals of metallic titanium and an arc between one titanium and one hard carbon terminal.

F. W. Peek, Jr.: All corona measurements made on actual transmission lines are welcome and valuable additions to the data on this very important subject. Mr. Faccioli's measurements are particularly interesting because they were made on a line operating right at the *critical voltage*. It is difficult, however, to formulate laws governing corona loss from tests made on a line of this length, since, there are too many variables to correct for, as different elevations at different parts of the line, different temperatures and weather conditions along the line, different voltage at the two ends, etc.

Undoubtedly the best method to determine the laws governing corona formation is by means of investigations on a short experimental line erected to represent practical conditions, and to supplement these investigations by extensive laboratory work. We have for the past year or more been carrying on such a study. An experimental line was erected representing standard practice. An approximate sine wave voltage up to 250,000 was available, and means were arranged for varying the spacing, size of conductor, etc. It was also arranged so that work could be done under all sorts of fair weather and storm conditions. Power measurements were made directly on the high side, eliminating error due to transformer losses.

These investigations show that the loss varies directly as the square of the excess voltage over the *disruptive critical voltage*, and directly as a frequency. Thus:

$$p = a f (e - e_0)^2 \qquad (1)$$

where p = kilowatt loss.

e = kilovolts line.

c is a term varying with the size of the wire and spacing.

f = frequency.

e_0 we have called the *disruptive critical voltage*. e_0 is much lower than the *visual critical voltage*, e_v, for small conductors and approaches e_v in value for large conductors.

Digitized by Google

Theoretically no loss should occur below the *visual critical voltage*, e_v loss does occur, however, due to irregularities, dirt, etc., on the surface of the wire. For line voltages near e_0, the loss is greater than given by equation (**1**) for large wire, and less for small wires. This small excess loss is due to " dirt " and is apparently represented by:

$$p_1 = g\, e^{-h\ (e_0 - e)^2} \qquad (2)$$

Curves taken over a very wide range show no change in e_0 due to humidity. Temperature changes show that e_0 varies inversely as the absolute temperature.

Snow, rain or sleet storms lower the voltage at which corona

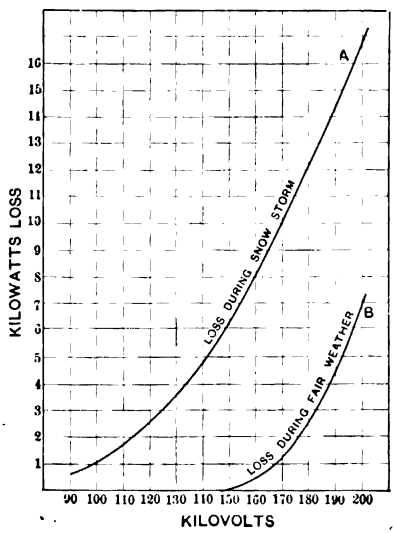


FIG. 1.—Corona loss

forms to a very great extent and increase the loss. Wet wires due to heavy fog also show a decided decrease in e_0. The effect of storms should be seriously considered in the design of transmission lines. Looking at Fig. 1: curve *A* shows the total measured loss during a snow storm, curve *B* shows the corresponding fair weather loss.

L. T. Robinson: With reference to the work these investigators have been able to do with the oscillograph, it seems to me that it is very unfortunate they have not been able to get better results, with what appears to me to be such a good tool; that is, I think it is extremely unfortunate that the apparent reproductions are not reproductions at all, but that they have been drawn, presumably with fidelity, but we do not know

Digitized by Google

that they have. It has nearly always been possible to get—I believe we have been able to demonstrate this without question—a good clear, definite, original reproduction that carries all the original data with it, I would like to take what little time is at my disposal in this discussion, to protest against the use of redrawn oscillograph records where the originals can be used, which I believe is in almost every case, possible. If redrawing must be done, it should be done in a way so that it has no deception about it—that is, a black line on a white ground, showing that it is not an oscillograph record but something else. We would then avoid all complications, and if we saw one of these black lines on a white ground we would simply believe as much of it as we saw fit to. There are many points that may come up in checking records that are not of interest, perhaps, to the observer who makes the records at the time. If we reproduce the actual record it has the advantage of being there always, and some one who reads the paper at some later date may find something in it that entirely escaped the original observer. It is just the same as including the actual data on which the observations were based in connection with any curves that may be drawn—which was referred to previously—this I think should always be done. If the original data interferes with the smooth flow of the text it should be included in an appendix where any one who cares to verify the curves, etc., can refer to it at any time.

Chas. F. Scott: All these papers are exceedingly interesting as they deal with a subject of combined theoretical and research importance, which is also of very great practical importance. They attack the real problems in transmission work. Mr. Creighton's paper is one of the most comprehensive papers that has been presented dealing with the very great practical difficulties and problems in what is now the greatest factor in transmission work, the continuity of service. It not merely states a problem, but gives the solution of it also. The paper by Messrs. Burkholder and Marvin, dealing with tests on the Southern Power Company's line, in conjunction with the paper of Mr. Creighton, shows pretty conclusively the operation of this method under actual service conditions. We are fortunate to have presented from another source, a line of parallel work closely following the one explained by Mr. Creighton, which, as I understand, has been in use on the important and extensive lines of the Niagara, Lockport and Ontario Power Company. All this means progress, progress of the most substantial and best kind. It is the direct proof of what I was saying this afternoon as to the present attitude of the large manufacturing companies towards the practical operating problems. This is not directly a commercial problem of the manufacturing company, it is rather a problem dealing in the large and broad gauge way with the industry, by which electric service may be made more reliable, and after all it is the final object of all our work to give better service. The relation of the manufacturing company

Digitized by Google

towards this work is not a narrow commercial one, the problems are studied in the broadest way, and time and ability and money are directed towards their solution. All those engaged in high tension work will be much profited by the papers which have been presented here at this session.

G. Faccioli: I will answer quickly some of Mr. Mershon's questions. The volts were measured on the secondary of the step-up transformer. The transformer was a 2 500-kw. transformer, and the voltage was measured on the secondary side. However, some of the tests were checked by using a spare 2,500 kw. transformer as a potential transformer connected across the high tension line, and measuring the electromotive force on the low tension side of the transformer. This is a method which has been advocated this afternoon. The charging current was measured on the low tension side. It is not exactly the charging current, but the difference between the charging current and the exciting current of the transformer.

I do not think any conclusion can be drawn from my paper on vapor product, because the measurements of the atmospheric conditions were taken at one point of the line only.

Mr. Mershon says that the lower part of the curve might be in error, and that the method of determining the critical voltage by the point where the two curves meet is uncertain.

The method which I propose, to determine the critical voltage does not consist in taking the point where the two limbs of the curve meet, but in observing the point where the curve, given by the quadratic law, cuts the axis of the abscisse. I believe this method of determining the critical voltage is much more accurate and positive. Furthermore, the lower part of the curve may be uncertain, but no attempt was made to find an equation for it. At 97.5 kilovolts, where the quadratic law begins, the line losses were so much higher than the transformer losses, that the results appear reliable. Regarding electrostatic effects in the wattmeter, the current coil was connected to the potential coil to eliminate such effects.

E. E. F. Creighton: Although we are really retracing the oscillograms, we find we can better reproduce them by tracing them. We try to do it faithfully, and if we do miss anything, it is better to have the loss than to have oscillograms which you cannot read at all. I think the better way would be to print the oscillograms black on white, and get better results. I think that is being considered now by publishers. I want to express my appreciation of the work done by Mr. Nicholson. He certainly has added much to the value of the work in transmission line protection.

Digitized by Google

DISCUSSION ON "OIL-BREAK CIRCUIT BREAKERS". SCHENECTADY, FEBRUARY 16, 1911. (SEE PROCEEDINGS FOR FEBRUARY, 1911).

(Subject to final revision for the Transactions.)

B. C. Jamieson: The subject of oil breakers is a very comprehensive one, and, as the title implies, all important is their efficacy as an energy rupturing device. Because of the extent to which they are used and the great amount of power behind them, moderate voltage breakers of high ampere capacity, such as are commonly employed on our large urban distribution system, are the most interesting.

Now with all the technique of operation aside, if the generally recognized limitations of this type of breaker could be removed, it will be conceded that the general switching and protective systems of large power stations would be simplified, and that expensive expedients, such as power limiting devices, would be necessary to a lesser extent. In other words, if it were possible to design a breaker which would instantly remove a member of the system, immediately it became faulty, without injury to the system, we would have the ideal breaker.

The outline of the basic principles, upon which the breakers described in the paper are designed, indicates that the development has been along entirely different lines. Referring to the curves given as the short circuit characteristics of an alternator and applying the switch operating principles, shown therewith, to a large system, consisting of five 14,000-kw. units, it will be seen that the operation of the breaker follows the period of maximum disturbance. The following questions naturally arise, what is to become, during this period of maximum disturbance, of our highly sensitive synchronous system of converters and the like? How much does the general structural reinforcement on the whole bus and switch system, under liability of this current necessary to safely carry these enormous current values, cost? How do we know that these characteristics apply at all when faulty insulation is the cause of the breakdown?

Attention is drawn to these points with a view of inducing the consideration by manufacturers of a type of automatic breaker which will prevent these abnormal current values. The value of such a device, combined with the absence of any assured limitation which might prohibit its development, amply warrants an effort in this direction.

E. M. Hewlett: The main point that does not seem to be appreciated by everybody is that with large generator capacity, switches must be designed to take care of whatever the bus bars will give them. Where the switches have a time limit, the time should be chosen so that you can get on the lower part of the curve shown by Mr. Merriam in Fig. 6, where the current rush is say three or four times the generator capacity. In that way you open the switch at a point where the current is limited.

Digitized by Google

If it is necessary to open the circuit instantaneously on very large powers, this can be done by making the switch large enough to do the work, but where economy of design in the station is required, you should put in a time limit, and also perhaps reactance, to bring down the work required to be done by the switch. In some cases, you can make the feeder switches smaller and have them take care of a certain amount of power by putting relays on them. This will permit the switch to open up to the power that it is able to operate under. Above this point, these relays will make the switch fail to operate and throw the work back on the main switch, when you can stand the interruption of service for a few moments on account of the economy of first cost of the station.

In reference to the rupturing capacity of switches, Mr. Merriam pointed out the baffle plate in Fig. 7. This baffle plate arrangement holds the oil over the contact and seems to be the simplest and most efficient way of keeping the oil there.

We have under consideration the making of a recording device for some of the large stations, so that we could get a record of short circuits in order to know really what occurs. We hear every once in a while that a switch has opened a very large amount of power successfully, and then we hear that a similar switch has failed on a comparatively small amount of power. There is too much personal element in these reports, so that we are laying out a device in order to learn the actual current conditions at short circuit. This, I think will help a great deal in our research work.

L. C. Nicholson: The principal lesson learned from extended experience in operating oil switches on high power circuits of medium voltage is that it is prejudicial to the successful operation of the switch to cause it to open several short circuits in a short time. Switches of approved type are apt to operate successfully once or sometimes twice within a few minutes, but damage to them will occur if they open severe short circuits in quick succession. This appears to be due to carbonization of the oil in the vicinity of the contacts, rendering the oil ineffective until the carbonized particles have time to settle to the bottom of the switch tank. This settling requires several hours.

As Mr. Merriam points out, a circuit breaker is favored if there is a time lag which prevents its opening on the first rush of excess current. We have found that a time limit of at least two seconds is required to insure the successful opening of a breaker under short circuit conditions.

W. L. R. Emmet: Many years ago I devoted a great deal of my time to oil switches and circuit breakers, but have not followed the subject very much lately, and I do not think I have much to communicate at the present time—the size of some of the circuit breakers recently built is very large, the designs being made to break the tremendous rushes of current which may occur on systems as now constituted; I think the circuit breakers have got about as large as they ought to be, and that further

Digitized by Google

avoidance of trouble should be accomplished by limiting the amount of current likely to go through any circuit, by the use of reactances and other means. This is now being done to a large extent, and I think that the growth of circuit breakers, as regards their size, will probably stop. These devices have been designed with a view to standing very high pressure and keeping the oil in contact with the break when it is possible to do so, but of course there are limits to this possibility and some of these devices which have been very strong, have been blown to atoms by some of the short circuits which have occurred. Many of the gentlemen in this room do not realize the extent and violence of some of the short circuits which have happened in different parts of this country. We had a short circuit in the Fiske Street Station in Chicago, in which the repulsion of the cables ripped many feet of clay ducts out of their masonry setting.

A Member: I would ask Mr. Merriam one point about the necessity of inspecting the oil. He speaks of that point, and I would like to know just how much consequence that has proved to be in practice. That is to say, has it been found really necessary to test the oil periodically, and if so, what does that amount to? I should rather infer from the theory of the operation of the circuit breaker that the chances for carbonization of the oil are so small that the dielectric strength of the oil would decrease very slowly. I should like to know if Mr. Merriam can give any real facts on the point.

R. D. Mershon: I desire to ask of Mr. Merriam, what measurements, if any, have been taken, or experiments made, to find out the effect of temperature alone? I wonder in the case Mr. Nicholson spoke of, how much of the effect is due to temperature and how much to carbonization of the oil. In the case of some of the short circuits, I should think the oil would have a chance to get heated up pretty well, even with one opening of the switch.

C. J. Barrow: Mr. Merriam brings up in his paper the question of power factor, and states that with decreasing power factor the tax on the circuit breaker is very much increased. Yesterday we were talking pretty generally on the matter of placing reactances in bus bars and in generator leads, in order to limit the stresses in the generator and also the tax on the oil switch. It would seem, on looking into the oil switch phase of the matter, that putting a reactive coil in the circuit will not decrease the tax on the switch in proportion to the decrease in current effected.

In the first place the decreased power factor resulting causes for a given current ruptured an increased tax on the switch due to causes which obtain in any low power factor circuit—when the current reaches zero value and arc is interrupted the voltage at that instant available across switch break tending to maintain arc is greatest when power factor is a minimum. The tax is further increased due to the fact that a potential piles up across the reactive coils on short circuit, which when current is inter-

Digitized by Google

rupted appears across switch break and renders arc more persistent than is the case when generator terminals are short circuited direct. Considering the time-current characteristic of short circuit, Fig. 6, the effect of reactive coils will be to prolong the time required for current to reduce to normal short circuit value, so a switch with definite time lag will where reactive coils are used be called on to rupture a greater current value.

It should be noted in this connection that the falling away of current from a high value at the instant of short circuit to the normal short circuit value results of the " killing " of the generator field by short circuit currents in the armature. Until this " killing " process is complete the original field flux (built up before short circuit) is present in part, but bucked out of the armature windings by excess armature current, and a switch called on to rupture current under such conditions will be under a tax more than proportional to the current ruptured because when current is suppressed a voltage tending to reëstablish it becomes immediately available, the field flux now being free to take its normal path through armature windings. I think this point has a bearing on Mr. Hewlett's remark to the effect that a switch is at times greatly taxed by a system of relatively small kilowatt capacity and again on a larger system operates without evidence of tax.

In talking rupturing capacities it is customary to speak of the kilowatts ruptured as the product of the normal voltage of the circuit by the actual amperes ruptured. It seems to me that the instantaneous current ruptured by the voltage available to maintain it at instant of rupture is more to the point.

On the matter of insulation the insulation of any lead or terminal must provide against puncture and also against " flash-over ", *i.e.*, passage of dynamic arc through air around insulation from conductor to ground. In low-tension apparatus the latter consideration is readily taken care of by simply providing an air path, conductor to ground, equal to or slightly in excess of the striking distance of test voltage which the lead must meet. In apparatus for service at 60,000 volts and upwards it is not so easily provided against and considerations looking to the control of " flashover " become the determining factors in the design of high-tension leads. The matter of providing sufficient insulation to resist puncture is in such apparatus a minor problem.

I wish to bring up for discussion the factors which enter to induce " flash-over ". As is well known, an insulating surface will carry a charge. Considering a small area on the surface of a bushing it carries a charge just as would a piece of tin-foil placed over the area. The charge is determined by the location of the surface geometrically with respect to the insulated conductor and parts of ground potential. Likewise, another local area will carry a charge, the potential of which is determined by its position. An analysis will show that the difference of potential between these surface charges compared with the distance

Digitized by Google

of separation is greatest near base (flange) of lead. That is the surface potential gradient considering a path from the flange to the conductor over the surface of its lead is greatest at the flange. It is at this point that such a lead under potential gives first evidence of stress by corona, and later brush discharges and finally by sparking. The passage of a spark brings the points between which discharge takes place to a common potential and thereby increases the stress between these and surrounding points and so becomes progressive. It is a case of series breakdowns and its prevention a problem in potential distribution. The sparks are static discharges only. A spark lengthwise will induce transverse sparks and soon the whole base of lead is covered by a shower of static sparks, which practically "short circuit" the surface over which they strike. These sparks extend towards the conductor as the potential increases, presenting a path for dynamic arc—"flash-over"—at a much lower potential than would be required to produce flash-over in their absence. They are not the result of surface leakage, and are practically independent of the nature of the surface over which they discharge.

It has been the general practice to limit these discharges by interposing barriers (surface washers) in the path of the sparks Within limits this is a very successful expedient. In an ideal design the potential at any point on surface of a lead will be proportioned to its distance from the conductor and the flange. Approximating this condition in a practical way, desired surface potentials can be obtained by suitably proportioning the diameter of the lead throughout its length (when so proportioned resistance to puncture is amply provided for); or surface potentials can be determined by bringing to the surface at intervals ends of foils whose potentials are fixed by embedding in the insulating body concentric with the conductor. The final criterion of the efficiency of a design as regards "flash-over" is the relation which the striking distance of flash-over voltage bears to distance, conductor to flange over surface of lead. A lead having a 30 in. minimum air path, conductor to flange and showing a 300,000 volt test is evidently not handicapped by poor distribution of surface potentials.

H. W. Cheney: Mr. Merriam makes a general statement which I believe will be misleading to some in describing the action of oil circuit breakers. He infers that the current is always interrupted and reëstablished successively in drawing an alternating current arc in oil and that this action is continued until sufficient insulation is interposed between the contacts to resist the maximum voltage of the circuit. This action no doubt takes place when circuits of high potentials are broken on comparatively slow moving contacts. The oscillogram submitted by Mr. Merriam clearly shows that this action took place in the circuit breakers under test when the record was taken. In my opinion it is possible in a well designed circuit breaker to interrupt the circuit abruptly at the zero point of the current wave

Digitized by Google

without successive re-establishment of the current flow by means of rapidly moving multiple break contacts, especially on circuits of medium potentials. I submit herewith in support of this statement some oscillograms made during recent tests under my direction on a 200-ampere circuit breaker.

Fig. 1 shows an oscillogram taken at the point of current rupture on a circuit of 462 amperes, 2360 volts, 60 cycles. The

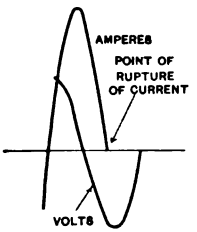


FIG. 1

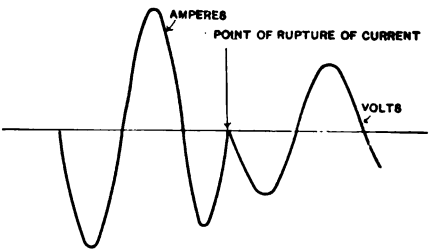


FIG. 2

voltage is connected across the line on the load side of the circuit breaker and the oscillogram clearly shows an abrupt interruption of both current and voltage waves.

Fig. 2 shows an oscillogram taken at the point of current rupture on a circuit of 384 amperes, 2400 volts, 60 cycles. The voltage is connected across the contacts of the switch, and the oscillogram shows an abrupt interruption of current wave at the

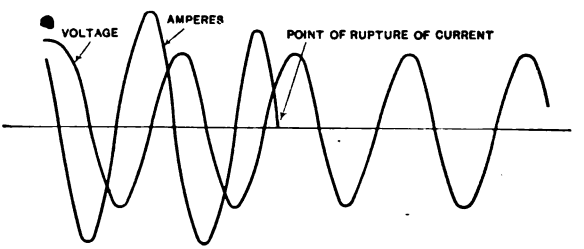


FIG. 3

zero point and also a simultaneous establishment of voltage between the contacts.

Fig. 3 shows an oscillogram taken at the point of current rupture on a circuit of 397 amperes, 2320 volts, 60 cycles. The voltage is connected on the generator side of the switch and the oscillogram shows an abrupt interruption of the current wave at the zero point. It also shows that the voltage wave is unaffected during rupture of the circuit.

The circuit breaker which was under test at the time these

Digitized by Google

records were made is provided with auxiliary arcing contacts which remain in contact until the moving element of the switch has attained considerable velocity. The moving element of the switch is comparatively light in weight and is spring accelerated at the point of contact separation so that a very quick break was obtained.

Mr. Merriam points out in his paper that high velocity of the breaking contacts is desirable, and I wish to say in support of this statement that my experience has shown that oil circuit breakers provided with multiple break contacts and high velocity moving elements at point of contact separation give the best results.

In many of the present forms of oil circuit breakers on the market the action in opening depends entirely upon the moving of rather cumbersome bodies through a comparatively heavy oil by means of gravity alone which results in very slow velocity at the point of contact separation, which is objectionable.

I would like to inquire the current, voltage, frequency and power factor of the circuit from which the oscillogram record illustrated in Mr. Merriam's paper was obtained.

A. S. McAllister: It is advantageous to limit the current on short circuit by means of reactance, yet it is undesirable for well-known reasons, to keep the reactance in circuit. Probably it would prove practicable to insert the reactance just when it is needed, leaving it out when it is not needed; in other words, to arrange the circuit breaker so that at the beginning of opening a reactance, on some such device, is inserted in the circuit to limit the current, and then the breaker opens the circuit only when carrying the lessened current.

Chas. F. Scott: We are having a demonstration of the universality of the laws of nature. Self preservation is the first law in apparatus as well as in animals. Yesterday in the consideration of transformers, nearly all the afternoon was spent, not in discussing the relation of the transformer to the power house, or to the consumer, and we were about to be discredited by having a long discussion on transformers without mention of hysteresis when Professor Adams came to the rescue and drew a hysteresis loop on the blackboard, but in discussing the self-preservation of the transformer to find what will keep it from burning up, or getting too hot, and what will keep it from distortion on short circuit.

In the paper on circuit breakers this morning, one of the most interesting curves shows the relation between the current in an alternator on short circuit and the time of opening the circuit breaker, and it was proposed that the circuit breaker wait a fraction of a second until the maximum trouble is over, and then come into action and do its part.

The question as to the time which should be allowed for a safety device to open the circuit is important not only from the standpoint of the circuit breaker, but from that of other apparatus. It may be noted that in Mr. Merriam's paper the

Digitized by Google

curve shows that in certain tests, the circuit breaker contacts parted one-fifth of a second after the relay was energized. If I recall Mr. Nicholson's statement correctly, he is endeavoring to get action within five cycles which is also one-fifth of a second, but he aims to have all operations completed within that interval, namely, only one-fifth of a second is to intervene from the time of the flashover, which may be 100 miles distance from the station, until the apparatus in the station comes into action and short-circuits a station of say 50,000 kw., and the short-circuit has been cleared and normal conditions have again been resumed. This interval is so infinitesimal that synchronous motors and rotary converters are undisturbed in their practical operation.

A general question which is raised is this—how far ahead should the designer look, in designing his apparatus? I mentioned the other evening some transformers which had operated for a number of years until the station was enlarged, and then the coils were found to distort. Mr. Emmet mentioned this morning certain switches which were believed to be perfectly satisfactory, because they operated well on some four or five large generators, but afterwards were found to be inadequate. Lightning arresters which were standard and operated satisfactorily for years were found inadequate when the capacity of power stations was increased. Now, when things are found inadequate, does it mean that the designs are defective and the designer is to be held accountable? Or is the fault due to something else? We certainly cannot look ahead, and be designing all our apparatus now for the time to which our president is looking forward, when the whole country will be interconnected with a 500,000 volt circuit, and practically unlimited energy will be available in each short circuit. It seems to me that the responsibility of the designer is to recognize what the actual specific conditions are, to properly adapt the different parts of the apparatus so as to operate successfully in the plant for which they are made, not necessarily in some other plant or some ultimate plant. He must understand the kind of conditions we have been considering here so that he can foresee and determine what the proper relation and strength of the different parts of the apparatus should be before they are installed, instead of learning them after trouble has occurred.

There is one other little interesting side note to which I desire to refer. The day before yesterday and to-day we have been treated to examples of the oscillograph. I believe all the papers at the Wednesday evening session, and the first paper this morning, are filled with oscillograms. Yesterday, in the papers on the transformer, the oscillograph was entirely neglected, until fortunately some one brought it in to save the day by referring to it incidentally in the discussion. The work of the oscillograph has given some new insight into these problems and makes their analysis a very different matter from what it was a number of years ago.

Digitized by Google

C. P. Steinmetz: The problem of the oil circuit breaker has always been and still is that of quick opening versus slow opening. If we can hold the contact closed until the generator field has gone down to its normal short circuit value, then we get the safest condition for the oil circuit breaker, but we do not put an oil circuit breaker in a system for the purpose of having the oil circuit breaker safe, but to save the system, and one of the reasons why we have the circuit breaker, is to protect the system from destruction by these enormous short circuit currents. That means that we must open the circuit breaker as quickly as possible to save the system. Where the short circuit current is limited by a long transmission line, so that its value can never be disastrous, then it is safe to hold on, but not otherwise. That means as quick opening as possible. There is a limit to that—it must not be overlooked that the circuit breaker is not there merely to open the circuit, but to open the circuit without causing any damage to the circuit, and if you open too quickly you get an oscillation—a good illustration is that of the condenser shunt in the Rhumkorff coil. Without it, the spark at the circuit breaker causes a slow opening, and you get a little bit of a thin spark, but with the condenser, you get a big spark in the Rhumkorff coil. That is the kind we do not want in our system. We get high voltages and other undesirable impulse forces more than we wish, and there is no need for creating them by abnormally quick opening of the circuit. Hence, we do not want a condenser which takes the momentary current rush away from the circuit breaker, storing it in the condenser, and then returning it into the system to add to the excessive power which at the same time is coming from the gnerator, and doubling up our strains by returning the stored energy into the system. We want a circuit breaker to open as quickly as possible to protect the system, but not quicker than it can open safely to the system, without producing disturbances in the system which may be dangerous.

H. L. Smith: There is one point that Mr. Merriam proposed in the paper, which is much condensed, and that is the question of the rating of oil switches, both for their heating limit and voltage tests. It seems to me it might be well within the scope of the Institute rules to take this matter under consideration.

One point which has been quite largely dwelt upon in connection with the rupturing capacity, which after all is one of the most important factors of the switch, is the question of power factor, and that is interesting from another point of view, although partially covered in Mr. Hewlett's remarks, and that is in different sizes of stations we may get different effects on the oil switches due to the variation of power factor—that is, it is conceivable that some of the smaller stations may give worse conditions than a station of 50 per cent larger capacity, and that, of course, introduces a problem that has to be considered in the selection of the oil switches. The question of rating these

Digitized by Google

switches has in the past been based almost entirely on the results of numerous tests, and presumably these tests have been made at relatively low power factors, consequently it appears that they are along the right line. I think that additional tests at much higher power factors may give us further information, which can be checked over and give us more complete and accurate data for future developments.

E. W. Rice, Jr.: I have not heard any reference to what seems to me to be a rather important factor—it has been stated that it is necessary to have the circuit open very suddenly. In modern central station practice reliability of service is paramount to all other factors. This means that everything is sacrificed to keep the current on the system. It is therefore desirable that the circuit breakers of the generators should be so arranged as to operate only after a considerable period of extreme overload or short circuit has existed. On the other hand, the feeder nearest to the short circuit should be arranged to open in a relatively short time.

It has been suggested, and I agree, that the proper method of operation is to arrange the system so that the current resulting from a short circuit will be automatically limited so that the flow of energy may be kept within a practicable amount. The permissible flow of energy will depend upon the character and size of the system. The best method of limiting this flow of energy in the case of a generator is to increase its internal reactance, but where this is impracticable, to insert additional external reactance in the generator leads. This reactance can be so adjusted as to limit the short circuit and bring it within the capacity of the circuit breaker. Similar external reactances can and should be inserted in important individual feeders so proportioned as to limit the flow of energy to the desired amount. If these reactances are properly designed and installed in a system the circuit breakers can then be provided with time limiting devices so adjusted as to maintain the current upon the system the maximum possible time. Naturally the generator circuit breakers will be adjusted to a longer period so as to open at a later time than the feeders, and as the outskirts of the circuit are reached the circuit breakers can be operated instantaneously as the amount of load which is then disconnected from the system is relatively small in proportion to the total load. Such methods are now being introduced in large alternating current central station practice, and the apparatus, generators, transformers and circuit breakers under such conditions must be made to successfully withstand whatever duty is placed upon them. By such means we can prevent the electrical apparatus from being destroyed and at the same time maintain the maximum continuity and reliability of service.

E. B. Merriam: Mr. Jamieson raises the point that a circuit breaker, in order to render proper protection, should open before the current in the circuit reaches its maximum value. In

Digitized by Google

a number of tests, it has been found that the rate at which the current increases on a dead short circuit is approximately 1,000,000 amperes per second, so that we can readily see the great difficulty presented in designing a circuit breaker to take care of this enormous current increment. The introduction of current-limiting reactances in series with the generator leads tends to limit the heavy current rushes which are present on short circuits and to lessen the strain on the bus and switch systems. This seems to be a much more effective method of protection than increasing the size of the circuit breaker to take care of abnormal conditions unaided.

Mr. Nicholson points out that in his experience successive operation is bad for circuit breakers. We find that the failure of oil circuit breakers after opening successive short circuits is due principally to the ignition of explosive mixtures which are formed from the gases generated by the arc combined with the air in the top of the oil vessel. The amount of these gases is dependent upon the volume of the arc and its duration and these in turn are dependent upon the current which the circuit breaker is interrupting together with the voltage across its contacts and the velocity with which the contacts part. This explosive mixture may be prevented from forming by replacing the air in the upper part of the oil vessel with an inert gas.

It has been our experience that the stresses in oil vessels rarely exceed 300 lb. per sq. in. In cases where cells have been disrupted as described by Mr. Emmet, this has been due not to the failure of the oil vessel but by the mechanical failure of the insulator in the top of the oil vessel. To our knowledge, the oil vessels have never been destroyed except from secondary causes.

The necessity for the frequent inspection of oil is more of mechanical than electrical importance and it is rather difficult to make a statement which will adequately cover all cases. Moisture affects the rupturing capacity considerably more than carbonization, while temperature effects are nullified after sufficient time lapses.

Mr. Barrow points out that the introduction of reactance coils into the circuit theoretically increases the tax on oil circuit breakers due to the lowering of the power factor of the circuit, the adding of the reactive kick to the circuit voltage and the retardation of current decay. However, it must be remembered that the introduction of these devices makes the short circuit current very much smaller so that the ultimate result is to actually diminish the tax on the circuit breaker.

The rating of oil circuit breakers with respect to their rupturing capacity has always been open to more or less discussion and as Mr. Smith suggests, it may be within the scope of the Standardization Committee of the Institute to consider this matter. However, in any case, it deserves careful study and all circuit breaking apparatus should be rated on a common basis.

Some comment has been made with respect to insulation.

Digitized by Google

On the lower voltages, this is very adequately taken care of by porcelain, but at voltages above 45,000, considerable experimental work will be necessary before satisfactory insulation is arrived at.

Mr. Cheney is quite right in stating that the current is not always interrupted and reëstablished successively in drawing an arc in oil. This action, however, is more apparent on high voltage circuits where the contacts move comparatively slowly. The oscillogram shown in Fig. 4 was taken on an oil circuit breaker when opening a circuit carrying 50 amperes at 6000 volts, 20 cycles, at unity power factor with the contacts moving apart at an average velocity of approximately 13 ft. per second.

Recent tests have shown that it is not undesirable to keep current limiting reactances in a circuit continuously since the loss which they impose is very small and the wave distortion slight.

Mr. Scott brings up the interesting point of how far ahead a designer should look in making up apparatus. Circuit breakers are built to take care of ordinary conditions and future additions to the generating equipment, when radically different, can either be taken care of by current limiting bus reactances or changing over the switching equipment.

Mr. Lichtenberg's comments in connection with the position of a circuit breaker relative to the generating station is worthy of consideration and in many cases, it is possible to use a comparatively small breaker on a large system if the location is sufficiently remote from the source of energy. Considerable information can be gained from the operation of oil circuit breakers considered as an energy dissipating device as pointed out by Mr. Lichtenberg.

Mr. Collis points out that it is English practice not to have large generator capacities so connected as to permit heavy current rushes at short circuit. There are power houses in the United States, however, whose normal bus bar capacity is approximately 120,000 kw. and it is possible to concentrate the short circuit energy of this system on any one of a number of switches. A conservative estimate of the instantaneous energy available at point of current interruption is approximately 1,000,000 kw. The advisability of concentrating this amount of power is largely a question of the character of the system since the practice of the New York Edison Company is to operate all of its alternators in parallel while the Commonwealth Edison Company of Chicago prefers to group its generating units.

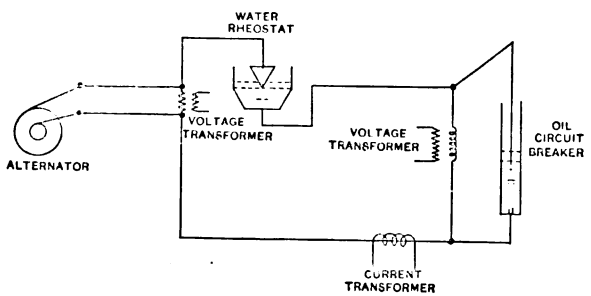
Current increments of 800,000 amperes per second are very common in the United States on short circuits and tests have recently been made where the current increment was approximately 1,500,000 amperes per second. Experiments have been made on switches opening a circuit within 0.01 second with very gratifying results but there has been no opportunity to place

Digitized by Google

these on large capacity systems. The oscillogram shown in Fig. 4 is representative of a number of tests and the accompanying sketch shows the diagram of connections for test during which this was taken. The system of connections shown in Fig. 5 is not intended to show the actual connections of any particular power house but merely to locate the various switches and circuit breakers in order to assist in the discussion of their various functions.

It has been American practice to advocate the use of non-automatic oil circuit breakers for use in generating units since it has been found that where otherwise equipped, they would continually disconnect themselves and seriously interfere with the continuity of service. However, in some cases the generators have been fitted with indicating reverse current relays with marked success.

The theoretical treatment of the transient phenomena during the operation of circuit breaking apparatus requires the consideration of a large number of independent variables. Such a



study is very difficult but important and deserves much attention.

Chester Lichtenberg (by letter): In discussing action, the author states that a distinctive feature of the oil immersed circuit breaker lies in the fact that when an alternating current which is maintaining an arc in oil passes through zero, the current is interrupted. There seems to be considerable difference of opinion among engineers concerning this point, but from numerous experiments which we have made, the conclusion has been reached that where the amount of energy is small, the voltage relatively low, and the current not too great, this type of circuit interrupting device may open the circuit at almost any point of the current wave. However, for voltages above 500, and currents in excess of about 200 amperes at commercial frequencies, it has been found that the current is invariably opened at the zero point of the wave. The author also points out that when the current is interrupted at the zero point, it remains so until the voltage rises to a sufficient value to puncture the oil

Digitized by Google

insulation which has been established between the contacts. This is absolutely true for certain conditions of voltage, current, and velocities with which the contacts part. However at power factors other than unity, it has been found that the persistence of the current tends to continue the arc, and prevent the interruption of the current at the end of each half cycle, although there is a tendency for this phenomenon to occur.

Under " Function ", the author states that an oil immersed circuit breaker should interrupt an electrical circuit without producing abnormal disturbances in that circuit. In addition to this very important function, the circuit interrupting device must assist in dissipating the stored electromagnetic energy of the system connected to it, and until this point is fully appreciated by designers and operators, the study of such devices will not advance beyond the primitive stage. This can be readily appreciated when we consider that any electrical circuit will have more or less inductance and capacity in addition to its resistance. Hence every electrical circuit will have more or less stored energy which must be dissipated when that circuit is interrupted. This dissipation takes place either at the point of interruption, or in the circuit itself, as a result of oscillations. When dissipated at the point of circuit interruption it is manifested principally as heat and chemical energy. Thus it may be seen that when systems are short circuited, and the circuit interrupting devices are opened and closed repeatedly upon this short circuit, the medium surrounding the contacts of these devices becomes heated. If this medium be oil, it is very likely that the flash point of the oil may soon be reached, and this will be followed by its ignition. This action will result in an increase of the internal stress in the oil vessels, and may result in an explosion if the device is operated while this condition exists.

In discussing time features, the author divides the total time interval between the instant the abnormal condition is apparent and the instant the circuit breaker is completely opened, into two parts. Most everyone who speaks and thinks of a circuit interrupting device, considers only the first portion of this interval. The second portion, that is, the time lapse from the instant the contacts part until the stroke ends, is equally important. Upon it depends the rapidity with which the circuit is opened. If this time is short, the arc produced is small. But if it is long, the arc is permitted to become very vicious, and may produce oscillations in the circuit. Again, if this time is too short, we will approach the condition of quickly interrupting a highly inductive direct current circuit, and thus also set up destructive oscillations. Hence there seems to be a definite velocity with which the contacts part, resulting in a maximum efficiency for the circuit interrupting device.

Referring to power factor and its effect upon a circuit interrupting device, we must remember that power factor is really another way of stating the difference in phase that exists be-

Digitized by Google

tween the voltage and the current in an electrical circuit. In addition, however, the power factor indicates the amount of stored electromagnetic energy in the medium surrounding the circuit. Hence, it may readily be seen that when the power factor of the circuit is low, other conditions being equal, the duty of the oil immersed circuit interrupting device is considerably greater than when the power factor is unity. In the former case the stored energy which must be dissipated at the switch when the circuit is opened is considerably greater than in the latter case. In this connection it is well to remember that circuit interrupting devices when placed very near large capacity generating units, must perform much more severe service than when placed a considerable distance away (electrically) from these units. When near the generators, the circuit breaker is called upon to dissipate most of the stored energy of the system, while when remote from the generators, a considerable portion is dissipated in the electrical circuit as a result of oscillations.

A. G. Collis: I notice that the author refers to a circuit carrying momentarily "*millions*" of kilowatts. There is no circuit carrying this capacity in connection with any power station yet designed, and if such a circuit were designed, it would not be advisable to rely on the efficacy of one switch to rupture such a circuit.

The engineer who designed a power station where a switch would be called upon to rupture "*millions*" of kilowatts would be courting disaster. The largest power supply in this country is equal to 35,000 kw., subdivided into groups. Even supposing that a switch on the bus bar side had to interrupt the total power behind it, the maximum rupture in such a case would not exceed 150,000 kw. Then again, the rupture efficiency of the switch would depend on the position of the wave at the moment of opening. The quality possessed by turbo-generators as at present designed for large outputs, *viz.*: the standing up to its work, has been realized in this country. This quality greatly increases the effects of a short-circuit (at present, the generators are not designed with large internal impedance), and switches have been designed to open the circuit as rapidly as possible, as the current increment at the instant of opening may be at the rate of 800,000 amperes per sec. (apart from the fact that the rapid opening of circuit may lead to excessive pressure rises). If, however, the current can be disconnected before it reaches a dangerous value, the rise of pressure may not be excessive. I have designed a switch that will open a circuit under the conditions referred to, and entirely disconnect the supply in less time than one half of the periodic wave, and I have taken oscillograms which show this time element to be 0.01 of a second.

There is another design of switch that will dissipate the rising energy during this time so that abnormal stresses have not to be interrupted during the switching off. This switch is designed so as to completely open the circuit in 0.02 of a second. Oscillo-

Digitized by Google

grams have been taken showing the results obtained with these switches and in every case, on voltages reaching to a pressure of 25,000 volts, the current has been finally interrupted at the zero point, in the first half of the periodic wave of the circuit. Hence, I doubt the statement that current passes in several waves when switching off.

I give below, some information concerning the records of tests attached hereto, and I enclose diagram of connections, Fig. 10, showing how the oscillograph was connected up.

It is particularly interesting to notice that the potential coil of the oscillogram is connected across the contacts of the switch, and seeing that one side is earthed, the wave of the potential is between phase and earth.

With regard to the oil-switch illustrated in Fig. 2, the development of this form of switch in this country, originated from the water-break-switch, and it is still used in connection with oil switches for direct currents in gassy mines, the water acting non-inductively on the circuit.

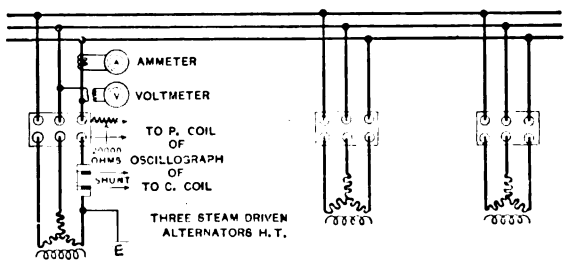


FIG. 10.—Alternating current high-tension induction test

The air break switch as shown in Fig. 3 is also interesting, but the oscillograms in Fig. 4 cannot be interpreted as there is *no* diagram showing how the oscillograph was connected up. It is therefore impossible to discuss the relative points of this oscillogram. As a matter of fact, it would appear to be impossible to get a curve such as shown, correctly, unless the current curve is the capacity of the current of the inductive circuit. The potential coil of the oscillogram must be at earth potential, and it appears to me that there is a discrepancy in the relations of the potential and the current curves. In the potential curve there does not appear to be any induced e.m.f. and change of current. This may possibly be due to the fact that the circuit has no appreciable capacity. However, in the absence of information relating to these curves, they cannot be discussed.

With regard to the diagram of connections shown in Fig. 5, I do not think that any engineer in this country would consider such a scheme as referred to. Here, simplicity is of primary importance, and the duplicating of groups, as illustrated

Digitized by Google

would be considered a complication. I may say that grouping, at Cot's Road Station, in this country, led to disaster. The operator did not consider the numbers of the groups, and paralleled all sets of the power station right across the bars, with the result that when the current transformer grounded it short-circuited the switch contacts, which formed practically a short circuit across the whole supply and caused the power station to be shut down for a time.

I do not agree with the author that hand-operated switches should be used for generators, but I advocate reverse relays that will open under a variable power factor—on a small percentage of reverse energy or otherwise, I have used a balanced system of protection.

I notice that the author advocates overload and differential time limit relays for circuits, but it is very difficult to get a discrimination of time values when running on a long feeder so that a short circuit at the end of the feeder shall be relieved without interrupting the entire feeder. Discriminating and overload relays show very little difference in time values under a short circuit condition, and they all invariably come out together.

Regarding protection for transformers, again, overload relays are not considered to be good practice, and in this connection, the high- and low-tension side is interconnected so that should a short circuit or an overload occur in the transformer itself, the transformer will be isolated both on the high- and the low-tension side, simultaneously.

Fig. 6 is not clear to me in respect to the time rated current which is given between zero and 40. I do not know what this figure represents. Apparently the highest peak on this short circuit characteristic appears in less than 0.01 of a time, which, again, is impossible, assuming that the rise is a current rise. If my assumption is correct, it is demonstrated that the highest peak occurred before the circuit breaker trip was energized. Therefore, the system put forward in the diagram proves it to be incorrect.

From the accompanying oscillograms, you will notice that the switch I have designed will open and finally interrupt the circuit in less time, as plotted out in Fig. 6, *viz.*: the circuit breaker trip energized 0.1 of a circuit completes (in my case) interruption in 0.01 of a circuit.

I notice that the stroke of the switch ends in 0.55 of a circuit, which is a dangerously long value, and in fact too long for satisfactory work.

Fig. 7 shows a motor operated switch for the voltage of 60,000 volts. I prefer a solenoid-operated switch, which has a more positive action and is noted for its absence of complications.

With regard to switches for voltages higher than 60,000 volts, I have put forward pneumatic operated switches, so that instantaneous rupture can be effected quicker than by the gravity opening of a solenoid switch.

Digitized by Google

Alternating Current Tests

The alternating current tests made were of two kinds:

1. High-tension with inductive load.

High-Tension Tests

Arrangement. The arrangement of the high-tension tests is shown in Fig. 10.

The plant consisted of three steam sets driving alternating current three-phase 6500-volt generators of the rotating field type. The sets were first run up in parallel, after which the steam was cut off from two of them, the remaining set driving them as motors.

As it was necessary that the potential coil of the oscillograph should be grounded, one phase was grounded, the pressure consequently being reduced to about $\frac{6500}{\sqrt{3}}$ in order that potential to earth should not be excessive. It varied, however, somewhat, during the tests according to the load. The distance between the generators and switchboard did not exceed 60 yd. so that any effects due to capacity would probably be negligible.

Since there was no return conductor to the neutral point, it follows that the return path for the current was through the remaining two conductors of the three-phase system. The switch in circuit on the high tension tests was of the electrical solenoid operated type, having cone contacts with a break of 10 in. per pole per phase. The whole of the contact mechanism moving in a vertical plane.

The power factor is stated on the diagram, this being the reading taken from a power factor indicator connected up on the circuit. The fact that the diagrams refer to the conditions of one phase of a three phase supply, and also that the voltage is measured between phases and not between one phase and neutral makes it a somewhat difficult matter to draw definite conclusions in respect to the induced pressures due to changes of current, from the records taken.

In all the diagrams relating to the tests on alternating currents, a photographic film must be considered as moving from right to left; that is to say, the current curve which is indicated by the heavy line, appears first, while the voltage shown by the thin line will make its appearance at the moment the current is interrupted.

Results of the Tests

See oscillograms Nos. 33, 34, 35 and 36.

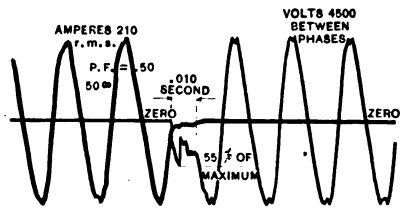
Remarks. Oscillogram No. 33 (210 amperes r.m.s.) shows that the current wave was interrupted as it was approaching zero value. There was an immediate inductive pressure rise, which appears to have been checked very suddenly probably on account of the fact that the impressed voltage wave is endeavoring to establish itself in an exactly opposite direction to the direction of the induced volts. On the other hand, it would appear that it

Digitized by Google

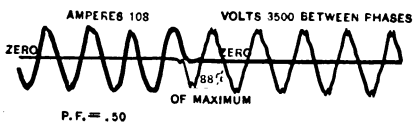
only required a period of time represented by one half of the complete period 0.010 sec. for the voltage wave to establish itself in a normal manner, and it will be noted that the first complete half-wave of the voltage curve reached its normal maximum value.

Oscillogram No. 34 (108 amperes r.m.s.)

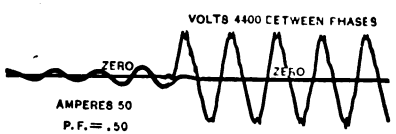
Remarks. In this record the current is interrupted at a point about half-way on the downward curve. It is interesting to



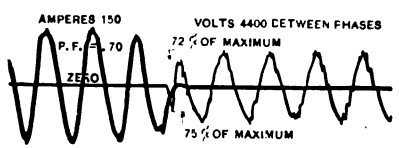
OSCILLOGRAM No. 33



OSCILLOGRAM No. 34



OSCILLOGRAM No. 35



OSCILLOGRAM No. 36

note the very sudden reversal of the e.m.f. curve, which again appears to be due to the impressed voltage establishing itself in the direction opposite to the induced volts. In this diagram it will be noted that the half-wave immediately following the rupture of the circuit does not reach the maximum value of the normal voltage wave.

Oscillogram No. 35 (50 amperes r.m.s.)

Digitized by Google

Remarks. It will be noted that the circuit is opened very soon after the maximum value of the current wave has been reached. In this case the first half-wave of the e.m.f. following the rupture reaches the maximum value under normal conditions, probably owing to the fact that the current broken in this case was comparatively small. The increase of amplitude of the current wave just before the circuit is opened is curious. It is the only record in which this phenomenon occurred. The only explanation the writer is able to offer is, that a growth of the current was commencing at this moment. On the original oscillogram the preceding wave appears to be slightly greater in amplitude, and that wave slightly greater than the one preceding it.

Oscillogram No. 36 (150 amperes r.m.s.)

Remarks. The circuit is opened at a point about half-way on the downward current wave, and here again there is a very sudden reversal of the e.m.f. while the first half-wave does not reach the maximum value of the normal wave.

Conclusions (High-Tension Tests)

In all cases the records show that the circuit may open at any point on the current curve, but after the current has died down to zero value, it never again rises on the other side of the zero line. It would appear, in fact, that in all cases, the oil rushes in between the contacts and prevents an arc being drawn out which otherwise might permit the current to rise again after it has passed through zero value. In one or two diagrams, notably No. 34 there appears to be a slight indication of a current wave having passed through the zero point at break, and risen to a very small value in the opposite direction before the current was finally interrupted but the evidence of the current having actually reached any appreciable value after passing through the zero point is not very definite, as in some cases the photographic records are not very clear, and although every possible precaution was taken to ensure that the diagrams should be reproduced as accurately as possible, the author does not wish to lay great stress on this particular point.

It would appear that the final break invariably occurs at or near to the point where the current curve would, in the ordinary course have reached the zero line. When making these tests, voltmeter and ammeter readings were taken, and where figures relating to current and voltage are reproduced on the diagram, these must be considered as the root of the mean square values of the alternating current of e.m.f. The exact maximum instantaneous values reached by the various curves have not been worked out, but in some cases it will be noted that where the normal maximum value is not reached by the voltage wave immediately following disruption of the current, the height of this wave is expressed as a percentage of the height of the wave under normal conditions. In no case do the tests show any abnormal pressure rises. In fact, the inductive rise on opening

Digitized by Google

the circuit in no case reached the normal maximum value of the impressed voltage, but it must not be forgotten that these tests were made with comparatively small currents, the greater current broken being 210 amperes, as indicated on diagram No. 33.

E. Zachrisson (by letter): Regarding the influence of power-factor and of different kinds of loads upon the rupturing capacity of an oil circuit breaker, I wish to make a few statements that may be considered as a modest attempt to attack the subject from a theoretical point of view.

The rupturing capacity of a given oil switch is determined by the size and the duration of the arc formed between the opening contacts. If the circuits to be opened are of the same capacity, but of different wave shapes, these factors will be the same until the point when the arc will break for the first time, *i.e.*, where the current passes its zero value for the first time after the opening of the contacts. Beyond this point, the conditions will differ materially for the reason that in different cases the arc has more or less liability to be reformed and that the current, if re-established, will reach different quantities. In the following, only the liability of the arc to be reformed will be investigated to some degree, this quantity being dependent on the voltage between the contacts in opening the circuit, at the point where the highest voltage appears between the contacts, on the moment of opening the circuit or if later; and whether the oil is much carbonized in the path between the contacts at an instant when there is a high potential stress in the oil.

The investigation may be carried out in following cases:

1. The opened circuit contains merely resistance.

The voltage being in phase with the current, it will at extinguishing of the arc, when the current equals zero, also be zero, and will after $\frac{1}{4}$ cycle equal the maximum value. (See Fig. 1.)

2. The circuit opened contains merely inductance (for instance induction coils or an induction motor with open circuited secondary).

When the current is discontinued when zero, the counter e.m.f. of the circuit will suddenly drop to zero according to the equation

$$E = L \frac{d I}{d t}$$

and the voltage across the opening contacts will equal the potential of the supply, which is at its maximum value at discontinuing the arc and will thereafter decrease (see Fig. 1). This behavior is very unfavorable on account of the fact that at maximum voltage the oil is about the same as that through which the current has just passed, and which is therefore carbonized and is not as good an insulator as before.

3. The opened circuit contains inductance and resistance in series.

Digitized by Google

In this case the theory is about the same as in No. 2. The main difference being that the voltage appearing across the opening contacts will amount to only $E_{max} \sin \varphi$, when $\varphi =$ phase angle of the circuit. See Fig. 1.

4. The opened circuit contains merely static capacity (not to be confused with " rotary condensers ").

There the equations apply

$$I = C \frac{d E_c}{d t}$$

$$E_c = \frac{1}{C} \int I \, d t$$

where $E_c =$ condenser voltage.

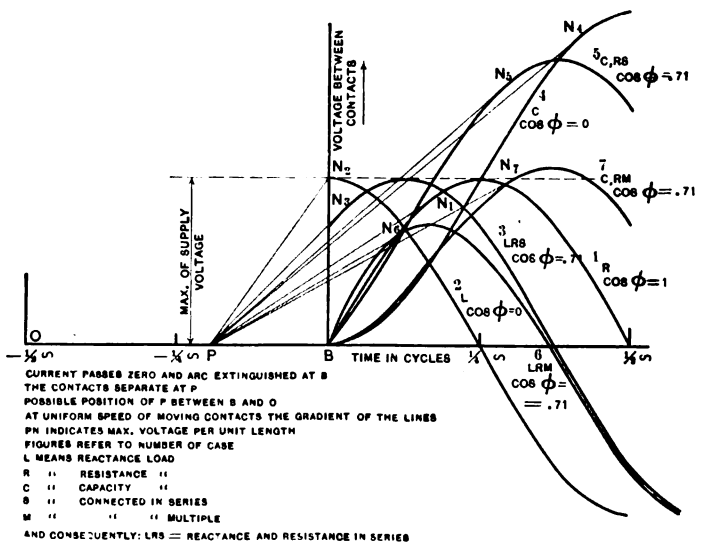

VOLTAGE BETWEEN CONTACTS
MAX. OF SUPPLY VOLTAGE
TIME IN CYCLES
CURRENT PASSES ZERO AND ARC EXTINGUISHED AT B
THE CONTACTS SEPARATE AT P
POSSIBLE POSITION OF P BETWEEN B AND O
AT UNIFORM SPEED OF MOVING CONTACTS THE GRADIENT OF THE LINES
PN INDICATES MAX. VOLTAGE PER UNIT LENGTH
FIGURES REFER TO NUMBER OF CASE
L MEANS REACTANCE LOAD
R " RESISTANCE "
C " CAPACITY "
S " CONNECTED IN SERIES
M " " " MULTIPLE
AND CONSEQUENTLY: LRS = REACTANCE AND RESISTANCE IN SERIES

FIG. 1

Accordingly, this voltage E_c is not dependent on the current at the instant when the circuit is opened, and because E_c equals the supply voltage in the same moment, no voltage then will exist between the opening contacts. But this electrostatic voltage found favorable in opening the circuit, will after one-half cycle increase the voltage between the contacts to the double maximum value of the supply voltage. This is rather unfavorable because if there is a reforming of the arc at the highest voltage, a heavy rush of current will cross a large space, burning the oil considerably. Fig. 1.

5. The opened circuit contains static capacity and resistance in series.

Digitized by Google

With the same arguments as for No. 4, it is readily found that the voltage across the contacts also starts from zero and that its maximum value will be $E_{max}\ (1+\sin\varphi)$. See Fig. 1.

6. The opened circuit contains inductance and resistance in multiple.

In this case (see Fig. 1 and 2) when the current passes zero and the arc is ruptured, there will still circulate a current $I_{max}.\sin\varphi.\cos\varphi$ through the resistance and the reactance, causing

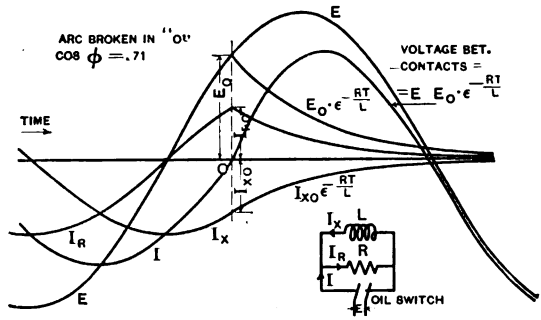


FIG. 2—CASE 6

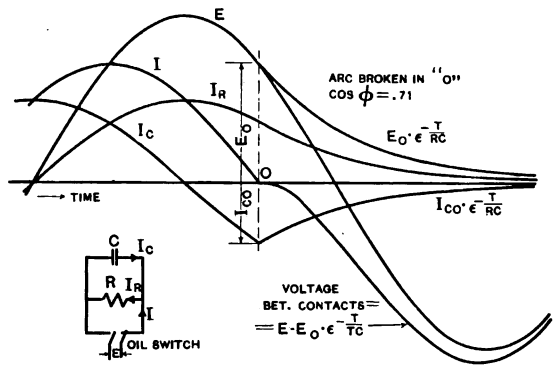


FIG. 3—CASE 7

a voltage $E_{max}\sin\varphi$. This current is decreasing, after the circuit being opened, according to the law

$$I_x = I_{max}\sin\varphi\cos\varphi\,\epsilon^{-\frac{rt}{L}}$$

and causes the voltage

$$E_x = E_{max}\sin\varphi\,\epsilon^{-\frac{rt}{L}}$$

The voltage across the contacts equals the difference between the supply voltage and this voltage E_x.

Digitized by Google

7. The opened circuit contains static capacity and resistance in multiple.

When the current through the switch (see Figs. 1 and 3) is zero, the condenser is still furnishing the current $I_{max} \cos \varphi \sin \varphi$ to the resistance. This current decreases, after opening the switch, according to the equation

$$I_c = I_{max} \varphi \cos \varphi \, \epsilon^{-\frac{t}{RC}}$$

and causes the voltage

$$Ec = E_{max} \sin \varphi . \epsilon^{-\frac{t}{RC}}$$

The difference between the supply voltage and E_c is the potential across the contacts.

8. The opened circuit consists of two synchronous machines in multiple.

The machines containing reactance and resistance in series, this case is identical with No. 3 except the great difference of the voltage appearing across the contacts of the switch just in opening is not the voltage of the machines, but the voltage drop in the machines, *i.e.*, the geometrical difference between the e.m.fs. of the machines. Here it is to be remembered that these e.m.fs. are created by a flux, formed by the difference between the ampere-turns of the field winding and of the armature reaction. For the magnetic flux is kept practically constant for some time after the disappearing of the armature current because of the effect of the currents, induced in the field winding.

Whether the current of the machines is leading or lagging, the only difference is that the current is discontinued at different points of the e.m.f. wave, so that the voltage across the contacts will show a little difference in wave shape.

9. The opened circuit consists of an induction motor.

If the rotor is open circuited, the case is identical with No. 2.

If the motor is running and the rotor circuit closed the conditions will be rather similar to those of case No. 8. For air breaking the current at the stator, the rotating flux is kept from disappearing at the same time as the current and is kept practically constant for some time by the currents induced in the rotor circuit. Therefore an e.m.f. is induced, that opposes the supply voltage and thus highly diminishes the voltage across the contacts.

Conclusions

1. The difference in the behavior of an oil switch at disconnecting different circuits of the same current is not so much due to just the power-factor of the circuit, as to other conditions, such as how much the impedance of the circuit consists of resistance, inductive and capacity reactance and how these are connected, and if the circuit to be disconnected contains rotating machinery or not.

Digitized by Google

2. A circuit containing only inductance or capacity gives the most difficult conditions for breaking the current, but the reasons why these two kinds of loads are both so very unfavorable are not the same.

3. At a given power factor of a circuit containing resistance and inductance or resistance and capacity, there are very different conditions if there is a series or a multiple connection.

4. The best conditions for a circuit, that contains no rotating machinery, are when there is only resistance, and if capacity or inductance are in multiple, with a resistance of suitable size.

5. The least difficult work is done by the switch in the case that rotating machines are disconnected. The conditions for this work do not seem to be the same line as when the circuit contained only impedance.

6. It seems possible that connecting a resistance of suitable size across the load terminals of a switch controlling a circuit containing chiefly inductance or capacity, will facilitate the opening of the circuit in spite of the fact that the total amount of current is increased.

Digitized by Google

DISCUSSION ON "HIGH-TENSION TESTING OF INSULATING MATERIALS," "HYSTERESIS AND EDDY CURRENT EXPONENTS FOR SILICON STEEL," "COMMERCIAL PROBLEMS OF TRANSFORMER DESIGN," SCHENECTADY, FEBRUARY 14, 1911. (SEE PROCEEDINGS FOR JANUARY AND FEBRUARY, 1911.)

(Subject to final revision for the Transactions.)

C. P. Steinmetz: Mr. Hendricks' paper on "High Tension Testing of Insulating Materials" is not simply a paper, but rather a compendium of our knowledge of the characteristics of insulating materials, the methods of testing, the difficulties met, and the errors to be guarded against, and how these errors may be avoided and reliable results secured.

With the rapid development of the electrical industry in the last ten years we have advanced to higher and higher voltages, and thereby the characteristics of the insulating materials have become of increasing importance, so that probably the insulations of our electrical apparatus constitute the most important materials which enter into the construction. This has been recognized by the Institute, more particularly by its Standardization Committee, and if we compare the first report of 1897, in which we find only a short paragraph dealing with high voltage tests, with a later report, that of 1907, we find in the latter quite an explicit discussion on the methods of testing, the different precautions and safeguards to be employed, on the use of the voltmeter and the use of the spark gap, etc. Nevertheless, even the 1907 report is already somewhat antiquated, and at least those engineers who have to deal with high voltage measurements, feel that the specifications of the Institute might be revised, and therefore a motion may be advisable to refer this paper to the Board of Directors for recommendation to the Standardizing Committee in studying and further investigating the methods of high voltage testing.

There are a number of important questions raised in this paper, and among them is the question of the spark gap. Theoretically the spark gap is the ideal and only correct method of measuring disruptive strength, as it measures the strain on the apparatus tested, by comparison with the strain on the standard material, the air, under standard conditions of experiment, the spark gap between needles under specified conditions. The great difficulty is in securing standard conditions, and herein lies most of the difficulty met in the spark gap method. When this method was standardized, we had no knowledge of the effect of transient voltages, on the difference in action of one dielectric and another dielectric, with different times of the application of voltage, which means that one spark gap may be equivalent to a testing material for one amount of energy, and a different spark gap for a larger or a lesser amount of energy, so that the entire field of transient voltages enters as a fundamental factor and indeed, as the most disturbing cause in the use

Digitized by Google

of the spark gap. Nevertheless, theoretically the spark gap is the most correct method, and it therefore requires further investigation, to see how we can guard against possible errors.

The voltmeter, after all, does not measure the disruptive strain, but it measures the effective value of the voltage, from which we can calculate the maximum value, and thereby the dielectric strain. This calculation is based on a knowledge of the wave shape of the voltage. It requires a sine wave generator. Practically all modern alternating current generators give electromotive force waves which are so nearly sine waves that the error in a high voltage test made by the use of such a voltage wave on the test piece, would be negligible. But it is not the shape of the voltage wave at the generator which is the source of trouble, but the great difficulty is to get the same wave at the testing piece. There intervenes the step-up transformer, carrying a great leading current full of higher harmonics, the transient effects of its capacity, etc., and herein lies the great difficulty with the voltmeter measurements, but as the author has shown in the paper, by using the voltmeter as close as possible to the test piece, this difficulty can be largely overcome.

There still remains the effect of transient phenomena, and one of the important results of this paper is, that the spark gap which measures the maximum voltage does not eliminate the danger of the error caused by transient or momentary voltage peaks, because there enters the time element, which is different with different shapes of spark gaps; is different with liquids, such as oils, and different again with solid insulating materials. From the investigations of the last years, this entire field seems to be thrown open again for further consideration, and in the recognition of this lies one of the most important features of this paper.

With the rapid increase of operating voltages, and the increasing demands for reliability of operation, the study of insulating materials has enormously increased in importance.

Henry Pikler: The papers of this afternoon deal with subjects which are interesting chiefly to the manufacturing and designing engineer. The few remarks I intend to make in connection with these papers are from such an engineer.

The subject of the first two papers, one by A. B. Hendricks, Jr., and the other by W. J. Wooldridge, is properties of material. This truly belongs in the realm of physics and should be treated by the physicist. The physical methods of investigating the properties of material are more refined and exact than the methods at the disposal of the commercial manufacturing engineer. I look at the papers presented in this light. In spite of the comparatively crude means at the disposal of the manufacturing engineer, the paper presented by Mr. Hendricks is a very valuable one not so much for the numerical data it discloses, but chiefly for the reason that it shows the means and ways which the manufacturing engineer should adopt and pursue for the purpose of obtaining reliable results.

Digitized by Google

To discuss the paper in detail, tests are given on liquids and solids. The materials entering into the construction of electrical apparatus of to-day consist of iron, copper and insulating materials. While copper and iron are not subject to deterioration under normal conditions, the insulating material deteriorates rapidly in comparison. A superficial reader of this paper is apt to get the impression that fibrous insulating materials are very important and of great value, because the paper deals with them at great length. As to the value of fibrous materials, I wish to state that I consider it unwise to rely on them entirely. The fibrous insulating material should be considered as a binder only. It is the oils and the varnishes which make the fibres really do the work. The less we rely on an insulating material of this type for the purpose of insulation, and the more on the mechanical disposition of the various parts to be insulated, the more durable will be the apparatus manufactured.

The old methods and principles of insulation I beg to be allowed to term " the ostrich policy ". The tendency was to *hide* the various parts to be insulated from each other and to wrap them up in a large mass of fibrous material like tape, paper, etc. My ideas of insulating modern electrical apparatus are as follows:

1. The proper mechanical disposition of the various parts which are to be insulated from one another. Smooth surfaces should be exposed between parts. Sharp corners and small radii should be avoided.

2. Small and uniform electrostatic capacities are to be sought for the parts to be insulated from each other.

The adoption of the first principle will result in a uniform and a low dielectric flux density between parts and every cubic inch of the insulating material between these parts will be under uniform stress, and therefore may be used most efficiently.

The adoption of the second principle will prevent the building up of a very high potential difference, between parts to be insulated which otherwise may act as highly charged condensers.

After the first two requirements have been fulfilled, the insulating proper should consist of the following:

3. The parts to be insulated from one another should be spaced at proper distances so as to present in the way of the discharge paths between the parts, either a wall of insulating material or a creeping surface of proper magnitude.

4. Extract the moisture from all fibrous material. Coat all the surfaces and fill all space with an insulating material of high dielectric strength.

It will be found that by the adoption of these principles in the method of insulating, a great deal of expensive material will be saved, and that the highest class of insulation of *lasting* qualities will be obtained.

I do not agree with Mr. Hendricks in his statement that the auxiliary winding on the testing transformer core should be used

Digitized by Google

in preference to the direct method of measuring the voltage either by a spark gap, or by other means. I consider his suggestion a fundamental error: What we want to know is the actual potential difference between parts of the apparatus under test. When we measure the voltage on the auxiliary coil of the test transformer, what are we doing? We measure the induced e.m.f. Now we know that the terminal voltage is quite different from the induced electromotive force for several reasons—As for instance, the electrostatic capacity of the testing transformer itself, the electrostatic capacity of the piece under test. All of this cannot be neglected even if the testing transformer has a very good regulation, but supposing the testing transformer *has* a very good regulation, then we might just as well go by the ratio and not use an auxiliary coil on the testing transformer at all.

I do not agree with Mr. Hendricks that a shell type transformer is better suited for the purposes of a high voltage testing transformer than a core type.

His reasons are the larger cross-section of core, and consequently the smaller number of turns in this shell type transformer. I do not see why in a core type transformer a larger section of core could not be used and consequently a smaller number of turns. Moreover, the core type transformer allows the high-tension windings to be distributed over a greater length, and consequently cut down the potential difference, the distances and the electrostatic capacity between parts. It admits of a better regulation. By cross connecting the two halves of the high tension winding, we will obtain an absolutely uniform and comparatively low potential difference between the two halves of the winding on the two legs.

The greatest value of this paper I see is that it will lead to the standardization of the properties of insulating material. This would be very useful, particularly from one point of view, that is, it will create a relation based on something standard between the purchaser and supplier of insulating materials.

As to the second paper by Mr. Wooldridge, on " Hysteresis and Eddy Current Exponents for Silicon Steel ", I noted with great interest the results published. I feel, however, that these results should be looked at with a great deal of skepticism, because this paper gives nothing else but the results of experiments. These results are quite different from the data we had on this subject in the past. There are absolutely no details of either of the methods of testing nor of the calculation given. Therefore, this paper does not admit of discussion.

The third paper presented to us is by H. R. Wilson, entitled, " Commercial Problems of Transformer Design ".

At the very outset of this paper a principle is enunciated which I consider fundamentally wrong. I cannot accept the statement that " one of the most important problems confronting a manufacturing engineer is the compromise between the design, which

Digitized by Google

in his opinion is best, but too expensive for competition, and the design which can be built to barely meet guarantees, and which can be sold for the lowest possible price." My experience teaches me, and I think that the majority of designers will agree with me, that it is a rule, almost without exception, that the most economical design is that which involves simplicity in construction. The simplest is always the best, and at the same time the cheapest. It does not follow as a necessity that if we put too much material into the apparatus that it will have the highest efficiency or that it will do the best. On the contrary, it will be found in most cases that economy in material will lead to high efficiency if the material is properly used.

I heartily agree with Mr. Wilson that " the designing engineer is at times compelled to cater to the idiosyncrasies of certain customers whose special requirements, experience has proven, are detrimental to good construction, but it will be furnished by competitors who are less conscientious in this respect." To this point I wish to add that keen business competition has led to excesses in this respect. For this reason I feel that the recommendations of the Standardization Committee of the A. I. E. E., with regard to definitions of output and guarantee, overload and heating should be more closely followed.

There is one paragraph in this paper referring to the finish or the outside appearance of apparatus. By all means a neat and good looking finish should be demanded in preference to a rough finish, for the simple reason that neglect of any one detail is apt to introduce neglect of other details, and in general is contrary to good discipline which requires care in every detail.

Ralph D. Mershon: I did not expect to discuss these papers at all, and do not feel qualified to discuss them, because I have not previously read any of them. The one by Mr. Hendricks looks extremely interesting, and I wish he had read it in full so that I might have been better qualified to take part in the discussion.

There is one point Mr. Pikler brought up, in which he took issue with Mr. Hendricks, but in which I do not agree with him. That is the possibility of getting correct voltage readings by means of a voltmeter testing coil. I think the accuracy of the results of such a coil will depend on where the coil is located: For instance, if it were practicable to wind the wire of the test coil beside the wire of the high voltage coil, we should unquestionably get on the voltmeter a measurement to all intents and purposes the voltage at the terminals of the high-tension coil A measurement which when corrected for the ohmic drop in the high tension, would give exactly this voltage. Now it is not practicable to so wind the test coil but it is possible to so locate it as to accomplish practically the same result.

In the high voltage measurements at Telluride 1896, the transformers used were not especially wound with reference to this method of measurement, but I selected one of the coils of the transformer for use as a voltmeter coil and from this coil

Digitized by Google

obtained the voltage readings and also the voltage for the wattmeter. The facilities for checking up the accuracy of this method of voltage measurement at Telluride were not of the best, but we made a great many test readings by attaching the power transformer to the line, putting various amounts of line on so that there were different amounts of leading current, reading the voltage from the test coil of the power transformer, and at the same time reading the line voltage by means of a step down or voltmeter transformer. So far as we could determine the measurement from the test coil was an accurate one. Later, in building the transformers for the high voltage investigation at Niagara, I wanted to have a great deal more elaborate means of insuring accuracy of voltage readings. I wanted to have a number of test coils arranged with elaborate care as to location and construction in the endeavor to approximate the results of a test coil with its wire wound turn for turn alongside that of the high voltage coils. Mr. Moody assisted me in that matter. In fact the final success of the transformers was largely due to the work that he and his assistants did in the design of them. He thoroughly convinced me, by a set of rather elaborate tests, that the method he proposed for using a single test coil instead of a number, was entirely effective. It was, briefly, that of locating the test coil in a position which was a compromise between the location if the test coil were wound directly on the iron and the location if it were wound in the manner first above indicated. The tests for determining the accuracy of the test coil so located were made under various conditions of load and power factor, and I had every reason to believe that the voltage produced by the test coil was, under all conditions, practically proportional to and in phase with the voltage on the high voltage terminals of the power transformer.

William L. Puffer: Mr. Hendricks has presented the results of experiments in the course of which those of us who have attempted anything of the kind realize that he has met and overcome some pretty hard problems. Some of us have been through these troubles and know the difficulties of making high-potential measurements, and I want to go on record as saying that I believe the most accurate method of determining the voltage of such high-tension transformers is by the method of the exploring coil. A good many years ago I used a special method which I devised as a part of a high-voltage testing set at the Massachusetts Institute of Technology and which has not been referred to here this evening. The transformer was wound with the high-voltage coil in sections of approximately ratios of 1-1-2-4, etc. A 2000-volt direct-reading static voltmeter was used and the exact ratios of the various coils measured. During any measurement this method permitted the determination of a fractional part of the high voltage by a method which was affected by all of the possible reactions of the testing current.

The ratio of the voltmeter reading to the maximum was de-

Digitized by Google

termined by the contact method, the Braun tube and finally, as the instrument was developed, by the oscillograph. The generator used was a Mordey, connected to a set of transformers used as a compensator to supply a suitable voltage for the primary side of the testing set. At that time I made many experiments to see whether the voltmeter method followed the spark gap method, and I am sorry to say that I could never get two curves nearly enough alike to represent good engineering practice.

I regret I have not had time to read the paper of Mr. Hendricks as there are many interesting points I would like to take up, and I thank you for the opportunity of saying these few words.

A. S. McAllister. The author has not defined his two terms, hysteresis and eddy currents. In separating these two he has made certain assumptions, and on the basis of those assumptions has separated the measurable losses into two parts. I wish to mention what seems to me the only source of change in the so-called eddy current and to criticise the method of separation. The eddy currents are produced by voltages, the value of which depends on the flux. Therefore, if the resistance of the path through which the current flows is constant, the eddy-current loss should vary as the square of the flux, other quantities being equal. Unless the so-called law of electromagnetic phenomena is wrong, the only thing that could have changed is the resistance in the path of the eddy current. Therefore, if the author's separation is correct, after the density reached the value of 8,000 lines per square centimeter the resistance increased, and hence the so-called change in eddy current loss if there was a change in this loss, was produced by a change in the temperature. Thus such a change is not inherent in silicon steel, except in so far as the change in temperature may change the resistance. This fact would seem, possibly, to be the explanation of the change. The change, however, is larger than one would expect from such a source, and I personally believe that the major portion of the change attributed to eddy current loss is due to the fact that the method employed in separating the eddy-current loss from the hysteresis loss would not bear close analysis.

L. T. Robinson: I have only a few words to say about Mr. Wooldridge's paper, they are along the line of Dr. McAllister's remarks, but at the same time I think no matter what way you look at it there is something in his paper after all. If you proceed along the line of analyzing the paper on the basis of what is wrong with the eddy current determination, there certainly is something wrong. If you reason that because there is some error in that portion of the paper the whole thing is wrong, perhaps, that position is tenable, but to support the facts given in connection with the hysteresis exponents, this work has all been gone over in an entirely different way by others and in connection with my own work. We have been able to show by standard

Digitized by Google

hysteresis loops, determined by ballistic galvanometer readings, that the hysteresis does vary throughout the limits substantially as given in this paper, although I believe the figures in the paper were determined in another way. While I am somewhat familiar with the way in which this work was done, I will not attempt to explain how the figures were arrived at, as Mr. Wooldridge will prefer to cover that when he closes the discussion.

There is, however, one point about these eddy currents which is of great importance, and which I do not think is fully appreciated; one which should not be neglected by research engineers and physicists until it is straightened out, that is, while the production of eddy currents and the way in which they are connected to core losses is theoretically covered in a certain way, these theories must be very incomplete, and inaccurate. We know by separation at fixed densities, with varying frequencies, what has always been considered to be a legitimate method, that we do get results substantially as shown in this paper, and we also know that these results cannot be thoroughly understood until we have some more complete theory to account for the discrepancies found.

In connection with the subject of eddy losses we have another fact which does not show anything except the incomplete state of our knowledge on this point, that is, we have silicon iron referred to in this paper which has a resistivity of approximately five times that of ordinary iron. We also have numbers of tests on transformers which show the eddy losses at a given density in a similar transformer have varied about in the proportion of 1 to 2.5 or 3. On the basis of any theory which has so far been brought out, the eddy current should be a direct function of the resistivity, and until we can in some way measure what it is that goes wrong and why it is that the results are so absurdly different from what the resistivity values would indicate, we should not be satisfied. I simply take this opportunity to present this as one of the problems that ought to be of interest to the pure physicist. Of course, it is of engineering interest too, but it is of such absorbing interest that I cannot see why the physicists who are practicing research work for scientific information alone have not tackled the problem with more strength, I certainly hope that something will be done that will lead to a solution of it, and that we may get the explanation of why, as Dr. McAllister says, "things are not the same as it seems that they should be."

George F. Sever: The paper by Mr. Hendricks I consider as one of great value to those in the educational field. Professors in the different colleges and universities have been testing insulating materials with every known apparatus, either as they have built them, or else bought them from the various manufacturing companies. They have placed a great deal of dependence on the spark gap method, either that which has been developed by Dr.

Digitized by Google

Steinmetz and advocated in the Institute Standardization rules, or that recommended by Mr. Fisher, as presented at the International Electrical Congress at St. Louis. Other professors have used the ratio method, measuring the voltage on the primary and trusting that the ratio between the primary and secondary held for all loads and all conditions and have reported to their clients that the breakdown voltage on these materials had a certain value. The sizes of the test plates have been different at different laboratories, and have given different results, so that material which was tested at one place, if we were sure it had identical construction, when taken to another place would test out at a different value, so that the whole situation seems to have been and probably is to-day very chaotic. While talking with the representative of the Electrical Testing Laboratories a few days ago he stated that the results they secured with plates of different forms and sizes gave entirely different results for the breakdown of insulating materials, because the voltages may not have been measured correctly or there were some other conditions in the problem. Now, if the results of Mr. Hendricks' investigations are correct, we will have a perfectly uniform method for the measuring of voltage on high tension work, and I think his paper will lead us in that direction and a final and definite method will be available for incorporation in the Standardization Rules.

Some time ago I wanted to measure high voltages at Columbia and was able to use a condenser method. Later I found the condenser method used up to certain voltages at the works of the General Electric Company, and I want to ask Mr. Hendricks if the condenser method could not be made a standard method, using two or more condenser plates in series and measuring the drop with a static voltmeter across one or more plates, as the conditions required; there have been condenser voltmeters built, and employed successfully. I would like to hear a discussion on the possibility of using condensers in series, the plates being of small size so as not to disturb the circuit too greatly.

I would like to ask if this method which is proposed is applicable to all voltages from the lowest, say 10,000 volts, which sometimes has to be used, up to 400,000, which seems to be the typical voltage indicated in Mr. Hendricks' paper. Cannot we use some simpler method for the lower voltages, say up to 50,000? You must remember that universities which sometimes have to teach high-voltage experimentation, do not have all the necessary funds for building or purchasing high-tension apparatus. If there is any other simple method, which does not cost too much for the universities to indulge in, I as one of the Professors would like to know about it.

J. R. Craighead: The real purpose of laboratory investigation of insulating materials is to secure data which may be applied to the design of insulated apparatus. Any satisfactory method of test used in the laboratory must therefore furnish results which

Digitized by Google

are directly comparable with those obtained by tests on installed apparatus. The use of voltage as the connecting standard would be satisfactory if a statement in terms of voltage applied meant the same insulation strain in both cases; but it frequently does not. Mr. Hendricks, for instance, speaks of limiting the wave of a generator to practically a sine by using a special generator and then by not overloading the generator beyond certain limits. Now, that is usually impracticable when you come to apply it to a large installation, such as testing cables on a city circuit. There the testing outfit is usually so designed that the maximum capacity of the transformers must be used to carry simply the testing load. This means that a certain variation from a proper wave shape is unavoidable in these practical tests.

With respect to the control of the apparatus, we meet another difficulty. The control of the apparatus by the generator field would be a perfect method if it could start from zero and go up to an unlimited quantity. But it cannot. It generally must start somewhere around 50 per cent of the full voltage of the generator. That presents difficulty in practical tests of large cable systems, for the reason that when you close the main switch on a cable system you throw a heavy capacity load on the testing outfit, and in some cases the voltage of the generator at once jumps up to much more than 50 per cent of normal, and there is a first increment of such size as is dangerous to the system. To meet a condition like that, it is possible to use an induction regulator, which can be arranged to buck or boost voltage, so that with a given generator the voltage can start at zero and run through any gradation to the highest limit specified. At the same time the induction regulator has considerable exciting current and some impedance, and the result is a certain distortion of wave shape, which need not be excessive, but which must always be reckoned with. Since these distortions of voltage wave form may cause differences in the stress on the insulation without changing the indication of the voltmeter, the voltmeter is not a satisfactory primary standard to connect tests made under widely varying conditions. Such a connecting standard should be practically independent of the usual changes of voltage wave form, giving a result under all conditions which depends directly on the stress on the insulation, rather than on any special function of the voltage. Up to date this primary connecting standard is the spark gap.

The spark gap is by no means perfect. I do not need to go into its difficulties. They have been taken up; but at any rate we are measuring a length with the yard stick when we measure the insulation strength of material by comparing it with the insulation strength of a known material, that is, air. The qualities of the materials are not strictly the same, but for the present it is the best we can do, and is an effort in the right direction.

Consequently, all we can ask is that some one should provide a better standard than this, and the better standard must be

Digitized by Google

associated not with the idea of how much voltage a thing can stand, because the standing of voltage means a great many different things of different kind, but it must mean a comparison of dielectric strength with the dielectric strength of some known material and the simplest and best known material is air.

In respect to the measurement of the voltage as a secondary standard the volt coil certainly works well, but where the voltages are not too high a potential transformer may be used on the high potential side; we are then enabled to take the voltage directly where it is applied, instead of at a point back in the circuit with more or less uncertain components between. This potential transformer can be made with practically any accuracy desired.

J. L. R. Hayden: The curves on Fig. 1 of the paper on hysteresis and eddy current exponents of silicon steel are very interesting and startling.

That the Steinmetz law of hysteresis does not hold for very low densities has been shown already by Dr. Steinmetz in his original paper. A decrease of the hysteresis coefficient at high densities has been observed repeatedly. Unexpected, however, is an increase as shown in Fig. 1. Further investigations on the cause of this increase would therefore be interesting.

Questionable appears to me the curve of eddy currents. Eddy currents are induced currents and the loss by them is an $i^2 r$ loss and therefore must be proportional to the square of the voltage, and to the square of the magnetic density. An exception could occur only if the resistance changed or magnetic screening took place. With a material of such high resistance as silicon steel this is not probable.

It therefore appears probable that the eddy current losses are so small a part of the total loss as to make their determination inaccurate.

F. M. Farmer: I had a few points that I intended to mention, but most of them have been covered by other speakers. I would emphasize the point Professor Sever brought up about the electrostatic voltmeter. We have used it and consider it successful and satisfactory for moderately high voltages, up to, say, 50,000, where the conditions did not prohibit the use of an instrument measuring mean effective values. I have in mind more particularly the effect and size of the electrodes. Professor Sever has spoken of this point. We are making an investigation now, and the results will be available in the course of a few months but the indications are that the size of the electrode does have a great effect on the apparent dielectric strength of thin materials, such as cloth and paper. The first thought is that when using large sizes of electrodes the electrostatic capacity may affect the wave form. We might get a peaked wave, the maximum of which determines the puncturing value and which is not shown by a voltmeter either in the primary, a voltmeter on the exploring coil of the secondary or an electrostatic voltmeter in the secondary. If we can use small specimens where there cannot

Digitized by Google

be any question of distortion of wave, I do not see any reason why the electrostatic voltmeter would not be satisfactory.

The method involving the use of the ratio of transformation when correctly determined and a voltmeter on the low tension side is also satisfactory.

I would refer to the cup and disk device which Mr. Hendricks speaks of. I cannot see where it has any material advantages over the apparatus most of us are more or less familiar with, using spheres. I believe the sphere device is known as the Skinner apparatus. Mr. Hendricks' suggestion means the use of less oil, but that is not ordinarily of much consequence, and as regards 45,000 volt transformers, instead of 60,000 volt transformers, that does not seem to be a very important point, because if you have a transformer that is good for 45,000 volts, the chances are it is all right for 60,000 volts for testing purposes.

Another point I want to mention is the work of the Committee appointed by the American Society for Testing Materials whose object is the Standardization of Tests of Insulating Material. That Committee is endeavoring to standardize not so much the kind of tests that should be made, but the methods of making the tests. As has been mentioned this afternoon, the whole thing is in a chaotic state. One man gets certain results by his methods and another man gets something entirely different on exactly the same material. It is hoped that the efforts on the part of that Committee to get information along this line will be encouraged by the members of the Institute, and they will give their assistance as far as possible. It is certainly a very important thing, and should be helped in every way possible.

H. L. Schermerhorn: I find in Mr. Hendricks' tests that the areas are rather small. It seems to me while it is very nice to have a fine scientific research made and the results given, of the insulating materials for our electrical apparatus, what we need now is something that is practical. In these days when so many young electrical engineers are coming forward to take up engineering work, without very much shop training, or opportunity to do some of this kind of testing work, they do not have the practical knowledge to take such results and bring them down to a practical basis—what I mean by that is they could not take these figures and use them in designs without serious results. Larger areas and larger number of samples tested under longer time periods give more practical results than the small samples under short time periods. The greater number of tests give very satisfactory results, and often times startling ones to the people who deal with them. The standardization of areas is an extremely important matter, and one which I would advocate the Institute to take up, and fix a standard for, so that all investigators could follow the same definite line.

E. M. Hewlett: The paper by Mr. Hendricks is more for the laboratory test, as I understand it. We need a quick test for

Digitized by Google

the practical work of the factory, and the spark gap seems to be the most convenient test for us to use. If we could have a new curve giving us the values of the spark gap on the upper end of the curve, up around 500,000 and 700,000 volts, I think that is what we are more interested in at the present time, in connection with the oil switches, etc., so it would seem as though for establishing the values of the spark gap or resistance across the high potential, a voltmeter or oscillograph in shunt with this resistance, and the necessary ground to make the test, could be used, and in that way new values for the spark gap might be plotted.

In reference to the testing of the liquids, that is, oils, etc., while they all break, down at a certain voltage when they are dry and in proper condition, if they are tested for time, there is a great difference. That is not mentioned in the paper. We should remember that there is a great difference in liquid insulation and in solid insulation in bulk, particularly under time test.

W. J. Foster: I had in mind to say a few words regarding the potential wave of alternators. I now hesitate as it has been brought out in the discussion that you can have almost any kind of a wave when you get on the other side of the transformer. I do want, however, to compliment the author on the thoroughness with which he has prepared his paper, and his attempt to have everything perfect, beginning with the potential wave of the alternator. The pictures of alternators that he shows are as comprehensive as the life of the industry. He shows an old high periodicity single phase revolving armature smooth core machine, which, as he says, has a good potential wave, and also the very latest turbine generator type with distributed windings in the field as well as the armature.

A well designed machine has a good potential wave, approximately a sine wave. There is quite a difference in machines designed for the same uses, between one of large capacity and one of small capacity when open slots are used. This is brought about by the fact that the breadth of the slot is about the same for a given potential in the very small machine and the large machine, whereas the air gap is much greater in the large machine. The potential wave is affected by the open slot and higher harmonics corresponding to slot frequency are likely to appear provided we do not take certain precautions. There are two or three ways of securing good potential wave. Such as the proper shaping of the pole face, so as to give the sine distribution of magnetism in the air gap; and looking out for the pitch of the windings rather than to use full pitch. One of the best ways of designing machines, even a small machine, such as would be in demand for testing purposes, is to avoid making the number of slots a multiple of the number of poles, in other words, design the machine for a certain number of poles and drop out two or more. This gives a Vernier arrangement in the super position of the potential waves of the individual coils, and in that way

Digitized by Google

practically as good potential wave can be obtained as any shown by Mr. Hendricks in his paper.

Charles F. Scott: I want to speak a word for the Standardization Code. It is neither an oracle nor an encyclopedia. Many people seem to think if it does not cover everything that there is something the matter with it. There have been two uncomplimentary comments this afternoon. One of them was in the paper in regard to transformers with water cooling, and referred to the temperature specifications and outside air. The conditions are obvious. The heat will be partly carried away by the cooling water and partly by the air in contact with the outer surface, and the temperature will depend upon the temperature of the entering water and the temperature of the surrounding air. The whole matter is one for individual specifications in the case of the particular transformer and not for general specifications in the Standardization Rules. All that the latter attempts to cover are certain principles and certain general conditions. Particular cases, especially when they concern large apparatus in which competent engineers are concerned, are left to the intelligent action of such engineers.

In Mr. Hendricks' paper reference is made to the fact that the present Institute specifications prescribe a uniform insulation test for all parts of the winding of a transformer, although in certain cases, it may be known that one end of the winding or the middle point will be permanently grounded. When the present Standardization Rules were in preparation, I undertook the task of drafting a paragraph covering cases of this kind. Objection was made to it for the reason that when a transformer is built, it may not be definitely known whether it is to be used on a single phase circuit or on a three phase circuit either in star or delta connection, or whether some point may be connected to the ground. Whatever the intention may be, the transformer is liable to be used in some way other than that for which it was intended. Hence, it was found impracticable to prescribe rules which would not be quite complex and liable to misapplication and misuse. It was, therefore, decided to make the general specifications so that they would serve for all transformers and to leave special specifications to the discretion of the engineers in special cases.

The principle involved is indicated in this sentence in the Rules:

> The voltages and other conditions of test which are recommended have been determined as reasonable and proper for the great majority of cases and are proposed for general adoption, except where specific reasons make a modification desirable.

C. A. Adams: I understand that the hysteresis and eddy current losses were separated in the ordinary manner by assuming that the former is proportional to the frequency and the latter to the square of the frequency. But after this separation, how were the exponents of Fig. 1 determined? Also, were the corresponding coefficients determined?

Digitized by Google

Wm. A. Del Mar (by letter): The subject of dielectric stress in the insulation surrounding a cylindrical conductor has lately given rise to considerable discussion at meetings of the Institute and elsewhere, and particular interest has been evinced in a curious phenomenon observed when dielectrics are subjected to powerful electric stresses, the dielectric acquiring temporarily some of the characteristics of a conductor without suffering any mechanical or physical damage of a permanent nature. This phenomenon was observed several years ago by Dr. E. Jona and again by Professor Alexander Russel, neither of whom offered a satisfactory explanation of it.

In order to fully grasp the significance of this phenomenon, it will be well to refresh our minds with certain well known facts and formulae relating to the quantitative expression of dielectric stresses in cables.

The following well known formula is based upon the assumption that the lines of electrostatic induction extend radially between the conductor and cable sheath and that therefore

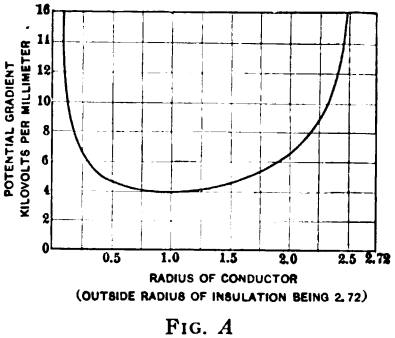


FIG. *A*

their density, or, in other words, the dielectric stress is greatest at the surface of the conductor.

$$K = \frac{V}{r \, ln \frac{R}{r}} \qquad (1)$$

where K = the dielectric stress at the surface of the conductor when the volts between wire and sheath equal V.

R = outer radius of insulation.

r = radius of conductor.

This equation is plotted as a curve in Fig. *A*. Its physical interpretation was discussed by the present writer after the paper on "Potential Stresses in Dielectrics", by H. S. Osborne in PROCEEDINGS A. I. E. E., December, 1910. Let it suffice to repeat that in the case of cables in which R/r is greater than 2.72, if the conductor were to grow in diameter, the dielectric

Digitized by Google

stress at its surface would decrease until its diameter became $\frac{1}{2.72}$ of the outside diameter of the insulation, after which the stress would increase. If instead of the conductor growing in diameter, the dielectric at its surface were to break down, the effect would be the same. The stress in the uninjured dielectric where it meets the injured part would decrease until the diameter of the injured part equalled $\frac{1}{2.72}$ of the outside diameter of the insulation, after which the stress would increase. If, therefore, the applied voltage is just sufficient to break down the layer of insulation nearest the conductor, the next layers of insulation will not necessarily break down, as the virtual increase of conductor diameter, due to the breakdown of the inner layers, will have eased the stress to a safe value. Hence, as pointed out by Alex. Russel, a partial internal disintegration of dielectric should be possible in such a cable without a complete puncture.†

An interesting contribution to the discussion referred to above, was that of Mr. W. I. Middleton, who pointed out that according to equation (**1**), the outside diameter of the insulation may be made a constant entirely independent of the size of the conductor and dependent only upon the applied voltage. Thus, referring to equation (**1**), assume that $\frac{R}{r}=2.72$ so that $r=\frac{R}{2.72}$ and $ln\ \frac{R}{r}$ becomes unity. Then

$$K=\frac{2.72\ V}{R},\ \text{or}\ R=\frac{2.72\ V}{K} \qquad (2)$$

This equation was shown by Mr. Middleton and Mr. Henry A. Morss to be amply confirmed by a great number of tests, so that it is in no sense theoretical or speculative; but it will be observed that its derivation from equation (**1**) depends upon the assumption that the inner layers of insulation are in some way broken down without injury to the outer layers. Mr. Middleton, however, said that " as far as Professor Russel's hypothesis that the dielectric near the conductor breaks down and becomes charred, is concerned, I do not believe it. In eight years in the testing room of a cable factory, I have never seen a cable that has shown mechanical change due to excess voltage in either rubber or cambric insulation ".

†Prof. Russel's conclusions have apparently been accepted by one of our leading manufacturers, upon whose specifications appears the following sentence: " Higher voltages, although not necessarily causing a breakdown of the insulation, are apt to *strain* it."

Digitized by Google

Other careful experimenters have said that they have never known rubber to break down mechanically or physically under high dielectric stress when the conditions of the test have precluded a complete rupture.

We are thus led to the anomaly that a formula is arrived at by theory and found correct by tests and then the theory upon which it is based, is apparently denied and contradicted.

The object of this contribution is to suggest an explanation of this apparent inconsistency.

A large number of chemical analyses of rubber compounds shows that there is always a certain amount of moisture present, the amount usually varying between one-quarter and one-half per cent by weight, which is equivalent to between one-half and one per cent by bulk. This amount is doubtless increased during the usual twelve or twenty-four hour immersion in water for testing purposes, so that a rubber compound may be regarded as permeated throughout its mass with minute particles of moisture. This moisture has a very perceptible effect upon the resistance of the compound as measured by the ordinary galvanometer method after electrification for one minute, it being the practice of many manufacturers to boost the resistance by placing the compound in a drying oven for a few hours before testing. This commercial drying process often doubles the resistance of the insulation, showing that moisture is present in sufficient quantities to radically affect its electrical properties. The specific resistance, however, is not the only electrical property affected by the presence of moisture. Rubber compounds usually have a specific capacity of about 2.5, while that of water is about 80, which is 32 times as great.* The significance of this, lies in the fact that when a dielectric of high specific capacity is placed in a field of electric force traversing a medium of lower specific capacity, the tubes of force tend to run through the foreign dielectric, because by so doing the potential energy of the system is decreased. If this dielectric is free to move, it can further decrease the energy by moving from its original position to one where the tubes are more thickly congregated, because the more tubes which pass through the dielectric, the greater the decrease in potential energy. The foreign dielectric will therefore be urged towards the part of the field where the tubes of force are the densest. In the case of the radial field between a cylindrical wire and a concentric sheath, the moisture in the dielectric will therefore be impelled towards the wire, with the result that the inner part of the insulation will become more impregnated with moisture than the outer, the particles of moisture ranging themselves about the core in much the same way that iron filings range themselves near the poles of a magnet. In order to study the effect of this condition, it will be well to refresh our memories about a well known experiment originated

*If permeated with electrolyte the specific capacity of water will be much greater than 80.

Digitized by Google

by Nicola Tesla. If two large conductors A and B (Fig. B) are separated by air, and the maximum possible difference of potentials set up between them, the potential gradient will be approximately represented by a straight line such as D. If, however, a piece of glass C, be introduced between A and B, the air will be electrically ruptured. The well known explanation of this phenomenon is, that the glass having a higher specific capacity than air takes a correspondingly lower potential gradient, thereby increasing the gradient in air beyond the rupture point as shown by curve E. The specific capacity of glass is about eight times that of air; if it were thirty-two times as great, the potential gradient would be as shown by curve F.

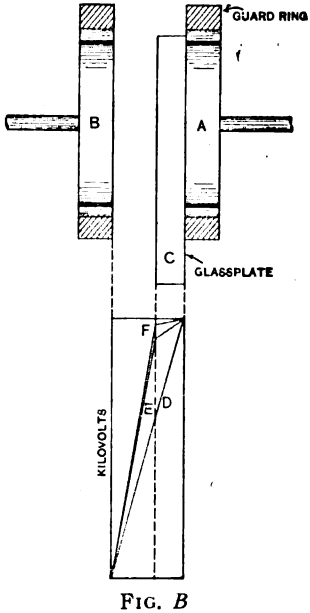


FIG. B

In other words the potential of the conductor A would virtually be carried to the outer edge of the glass.

This is possibly what happens in the moisture impregnated cable insulation. The potential gradient along the zones of moisture is practically zero, carrying the potential of the wire far into the insulation. The moisture is, however, not continuous, so that the equipotential lines are not concentric with the wire, but consist of a series of attenuated peaks having their minima at the surface of the wire and their maxima deep in the insulation. The inner insulation would therefore be unable to support a potential gradient, as shown by Mr. Middleton's tests, and yet would show no sign of internal breakdown, thus giving rise to the anomaly which has been fruitful of so much discussion.

Digitized by Google

If this theory is correct, the cable should show practically no increase of capacity when stressed to near the rupture point, as would be the case if the inner layers had been reduced to a conducting state, for the capacity is a measure of the number of tubes of force between the wire and sheath and this will not have materially increased, owing to the small proportion of the total dielectric which is occupied by water particles. That the capacity actually does not materially increase, was shown by careful tests made by Dr. Jona and others; and their results have been confirmed in the course of commercial testing by measurements of the charging current prior to breakdown.* Another requirement of the theory is that the occluded moisture must be free to move within the insulation. That such is the case, is known to those familiar with the phenomenon of water entering negative mains by endosmose,† and is also deducible from the rapidity with which moisture may be removed by means of a drying oven. This theory may also explain the well known fact, mentioned by Mr. Hendricks, that the dielectric strength of insulation such as rubber compound, is greater when electrified for a short time, than when the electrification is prolonged, because at first all of the rubber carries the potential gradient, while after the moisture particles have congregated, almost the entire gradient will have to be carried by the outer layers of insulation. Furthermore, after a certain time, the dielectric strength shows no further decrease, which is explained by the fact that all the moisture finally reaches a position of equilibrium, corresponding to the minimum potential energy. That a minute proportion of moisture has the effect of reducing dielectric strength to a remarkable degree, is well shown by Mr. Hendrick's curve for transformer oil, Fig. 21. The percentage by bulk of water in rubber insulation has been stated to be from one-half to one per cent. The effect of one-tenth of one per cent of moisture in transformer oil, is to reduce its dielectric strength to about one-seventh of its value when dry, and what is even more significant is that the greater part of this reduction is due to less than one part of water in 10,000, the further addition of water having but little effect. Analogy would lead one to suppose that a correspondingly minute proportion of water would effectually alter the dielectric strength of rubber and that additional water would have little or no effect.

It might be objected that this theory does not explain the Middleton phenomenon because the outer limit of the displaced water particles does not necessarily correspond to the radius $r=\frac{R}{2.72}$ and therefore the effect of the water particles would be to give an indeterminate reduction of the effective thickness of insulation. This objection would be fatal were it not for the

*Alex. Russel, November 7, 1907. Journal I. E. E. (London), Vol. 40.
†Journal I. E. E. (London), August 1908, p. 455.

Digitized by Google

following fact. By reference to Fig. A it will be observed that the curve A is almost flat for about one-third of its span. In other words, if the insulation be supposed to be divided into three concentric layers of equal thickness, and the outer limit of the moisture particles is anywhere within the middle layer, their effect in reducing the effective thickness of insulation would be practically the same as if they extended exactly to the radius $\frac{B}{2.72}$.

A corollary to be deduced from this is that rubber insulation may be susceptible of internal destruction without puncture, if perfectly dry, but the presence of moisture, even in minute quantities will prevent this action by affording a natural " grading " of the insulation.

The reader is again reminded that all this is mere theory and that experimental work is required to prove or disprove it. It is to be hoped that someone who is well equipped for the work, will undertake the required experiments, as the theory has a practical bearing on the manufacture and use of cables.

Digitized by Google

DISCUSSION ON "VOLTAGE REGULATION OF GENERATORS", SCHENECTADY, FEBRUARY 16, 1911. (SEE PROCEEDINGS FOR FEBRUARY, 1911.)

(*Subject to final revision for the Transactions.*)

H. G. Reist: I would recommend this paper to the careful consideration of engineers who design and operate stations, and call attention to the fact that the use of regulators in stations allows us to build generators having inherent regulation not as good as has been thought desirable in the past. The reason for desiring generators having poorer regulation was fully discussed this morning but I might repeat that it is desirable to have such machines to avoid excessive currents and thus endanger generators and other station apparatus in case of a short-circuit on the system. Reducing the flow of currents during short-circuits is of advantage in every respect except that it spoils the regulation of the system. In large systems this is usually of no importance and in small ones the potential can readily be maintained by means of regulators.

Carl J. Fechheimer: That poor regulation rather than close regulation of alternators is really desirable in a great many cases is becoming more and more the opinion of engineers. This applies especially to high-speed generators, particularly those of the turbo type, in which the size of machine is almost entirely determined by rotor heating and stresses, it being understood that these generators supply current for induction motors, so that the load of the system is inductive and the power factor rather low.

It is usually considered to be essential at the present time for generators to maintain their voltage at 25 per cent overload, 80 per cent power factor. It may be shown that the ratio of the maximum ampere turns in the field winding to the ampere turns in the stator at full load is nearly fixed for a definite regulation and for the amount of overload which the generator should carry at the power factor of the circuit, and still maintain its voltage. From this it will be seen that if the voltage regulation be very close it results in a rather large rotor or else great heating in the rotor; hence, from this point of view we can materially gain if we sacrifice regulation slightly, a voltage regulator being used.

As the size of units and transmission systems increase in their output, close voltage regulation is often found to be unnecessary, as the changes in load on the system are very slight compared with the combined output of the units supplying power to the system. In such cases the change in voltage is hardly sufficient to detect a perceptible change in the illumination produced by the lights on the circuits.

From another viewpoint, close voltage regulation would be undesirable as this also implies that in case of short circuit the damage which may be done to the end connections of the generators and to other apparatus may be considerable.

There is, however, one serious objection to having poor

Digitized by Google

inherent regulation when a regulator is used and that is, if the currents of the various phases of the generator be unbalanced, the voltages will be correspondingly unbalanced, with the result that the lights will burn dimly on one phase and brightly on another. While this may be remedied with the use of compensators, it is only done by complications which would be unnecessary were the generator to have closer regulation.

It is my opinion that reasonably good regulation is very desirable in small generators (up to 500 kilovolt-amperes) and that it becomes of less importance as the size of the generator is increased. In a 5000-kilovolt-ampere alternator, a regulation of 15 per cent at 100 per cent power factor and 30 per cent at 80 per cent power factor should be sufficiently close for nearly all cases.

E. F. Alexanderson: The Tirrill regulator is usually thought of as a voltage regulator, but I wish to call attention to the varied possibilities for its application. Ordinarily the regulator is adjusted so as to maintain constancy of a certain electric quantity, for instance, voltage, current, or combination of the two. This is done by balancing the attraction of the regulating magnet against a counter weight or spring pressure. In many cases, however, it is desired not to maintain the constancy of the voltage or current, but to regulate the relative magnitude of two electrical quantities, for instance, to regulate the relation of wattless current to energy current; in other words, automatic regulation of the power factor by a synchronous machine, or maintaining equality of the two voltages in a three wire system by a balancer set. In such a case the regulating magnet is not balanced against a spring, but equilibrium is established by the equal and opposite attraction of two magnets, or by the action between two magnets becoming zero due to the currents being out of phase.

There are numerous variations of this principle, and, in general, it is only worth while remembering that the regulator is an instrument which lends itself with only slight or no modification to the automatic regulation of almost any electrical quantity that can be measured.

Digitized by Google

DISCUSSION ON "THE REGULATION OF DISTRIBUTING TRANSFORMERS", "TEMPERATURE GRADIENT IN OIL IMMERSED TRANSFORMERS", "DISSIPATION OF HEAT FROM OIL-COOLED, OIL FILLED TRANSFORMER TANKS", "PROBLEMS IN THE OPERATION OF TRANSFORMERS", PITTSFIELD FEBRUARY 15, 1911. (SEE PROCEEDINGS FOR DECEMBER, 1910, JANUARY, FEBRUARY AND MARCH, 1911.)

(Subject to final revision for the Transactions.)

W. S. Moody: I will not attempt to contribute to any of the discussion, but I wish to point out one idea that has been specially in my mind in connection with the papers that have been presented this afternoon. Most apparatus, whether electrical or otherwise, requires some arbitrary or empirical formula to be used in its design. Transformers, among electrical apparatus, are, I believe, as little subject to these "cut and try" methods as any other class of apparatus, except for two characteristics that have been brought to the front in the discussion this afternoon—*viz.*, the calculation of the dynamic forces that must be resisted, and the predetermination of temperature rise.

For the first, we now have in the formulae recently developed the means of knowing what these forces are, and with this knowledge, taking care of them is a relatively simple matter.

When sufficient mechanical support has not been furnished for transformer windings, it has been due to an under-estimate of what these forces are likely to be, rather than any special difficulty in providing proper supports when the actual force to be encountered is known.

With reference to the second point—*viz.*, temperature rise, there has been a great lack of definite data. We can calculate a new transformer in nearly every other characteristic with great accuracy, but if the design is radically new, one could not, in the past, tell what the real capacity would be with a given temperature limit until tests were made.

Having determined the temperature by test, it is usually necessary to re-proportion the parts once or more to obtain the desired characteristics on the re-rated design.

To predetermine temperature rise one must consider a vast number of details, such as are considered in Mr. Weed's paper, and which have previously been neglected or allowed for in a very arbitrary way.

With such formulae as are discussed in Mr. Harper's paper, and such data and formulae as are considered in Mr. Weed's paper, I feel that there is no further excuse for the use of any "cut and try" methods being pursued in transformer design.

Henry Pikler: The papers we have just heard as some of the papers we heard earlier, interest probably the designing engineer more than the operator, since after all the operating engineer is satisfied if the apparatus in service fulfills the requirements of guarantees attached to it.

As to the various papers, Mr. Allen's paper on the "Regulation of Distributing Transformers" is a very able and clear presenta-

Digitized by Google

tion of the relation between resistance and reactance in the regulation of the transformer. A great many examples have been worked out and various formulas given to calculate the regulation, but in general I dare say I do not find the broad point of view from which the influence of both the reactance and the resistance could be clearly pictured. The following may be a clearer and simpler presentation of the facts: The regulation depends upon the mutual relation between resistance and reactance in the transformers; at loads of unity power factor the regulation is approximately equal to the resistance drop, and at loads of zero per cent power factor, it is approximately equal to the reactance drop; at power factors between the two, the regulation will be found between these two figures that is the resistance drop and the reactance drop combined.

Towards the end of the paper a method is given whereby good regulation may be obtained in transformers intended to be used for three wire distribution, lighting transformers. At this point it may be said with probably greater simplicity: In small size lighting transformers the resistance is the predominant component of the impedance. In larger transformers the reactances is of larger amount. Therefore, when we want to connect various parts of the transformer windings into parallel, so as to obtain proper three wire distribution and at the same time best regulation, in small transformers equal resistances in large transformers equal reactances should be connected in parallel.

I consider one of the most interesting papers, presented to us, that by Mr. Green on " Problems in the Operation of Transformers ". Anybody who has had a chance to install transformers, to observe them in operation and to note the various phenomena in connection with them will appreciate the complexity of these phenomena and the difficulty of their clear presentation.

One of the most frequent sources of troubles in connection with transformers is their installation. At this point I wish to call attention to the fact that while almost always the transformer is tested at the factory of the manufacturer, in the presence of a representative of the customer, afterwards the transformer is installed frequently by the customer himself. The transformer is often found satisfactory in every respect at the factory, yet, at its installation breakdowns are not infrequent. Causes of this may be various and I shall refer to them later on, but I desire to use this occasion for suggesting the adoption of some rules, if that is at all possible, whereby the customer be held responsible for injuries to the transformer when he does the installation after having tested and accepted the transformer at the factory. The manufacturer should be held responsible only when his representative does the installation.

The causes of the breakdowns in transformers may be divided into two great classes. (1) Internal causes in the transformer itself. (2) External causes.

Digitized by Google

1. As to the internal causes I believe that defects in design, electrical construction, insulation, will show up at the factory if the apparatus be tested rigidly. At the same time there may be defects in the manufacturing which develop a weakness in the transformers only after it has been installed and operated for some time. At the present time the use of solid compounds for impregnation of the windings is almost universally adopted. The solid compound marks a great improvement in the modern transformer because it makes those mechanically weak coils of which we heard so much this afternoon, stronger by cementing together the turns and the insulation between turns and layers in the winding. At the same time the application of this solid compound is not so easy as it may look at first glance. If not done properly there may be found bare spots in the winding which have not been reached by the compound. At such places the mechanical wear and the dielectric stresses combined may create injurious effects in the course of time.

Also improper drying out before installation may be the cause of a breakdown.

One very good point brought out in this paper which I believe hits the nail on the head as regards internal causes, is the suggestion that the electrostatic capacity of the parts of the transformer should be small.

It is very interesting to follow the history of the design of transformers and of the means suggested for their protection. Years ago we heard that the weakest element in a transformer were the first turns and they ought to be protected most carefully by insulating them more than other parts, it was earnestly recommended to put a choke coil in series with the transformer or use the choke coil internally or even to develop the first few turns as a choke coil. *Now* we hear that it isn't so much between the first turns where the breakdowns occur but between other turns or parts of one winding. It would be very interesting to take oscillograms for the purpose of obtaining the voltage distribution between the various parts of the transformer winding under various conditions as switching surges, etc.

Again in this paper we find reference to forces in transformers arising on short circuits; it is suggested that the transformer be designed with sufficiently high reactance in order to reduce the short circuit currents, and the resulting forces. At this occasion I wish to say that contrary to the statements made by previous speakers that the low regulation of the transformer is chiefly due to the customer's demands for such, my findings are different: Low regulation is a natural sequence in transformers of large sizes; with the generally adopted principles of design and the economic utilization of materials, we cannot help but obtain a decreasing reactance with increasing output. Furthermore, we mustn't forget that it is not the per cent reactance that should be considered in this problem but it is the numerical value in ohms. To make a large transformer of high reactance is not

Digitized by Google

so simple as it may seem at first glance. A high reactance transformer means an expensive transformer. It means a transformer with many more ampere turns than in a low reactance transformer. More ampere turns means more copper and copper is an expensive material; besides copper requires winding space, hence a bigger iron core, in other words a larger and a more expensive transformer. On the other hand, if the high reactance be created by increasing the space between primary and secondary windings, we again get a larger winding space and larger core; in addition a tremendous self inductive field will be developed between these windings which is conducive to high eddy currents, heating and a reduced efficiency.

2. As to the external causes of breakdowns I wish to emphasize very strongly that in this respect the entire power system must be considered from the prime mover to the distributing apparatus. Concentrated condensers in parallel with the transformer created by neglect of grounding supports of high tension wiring, switching apparatus, etc., can pile up tremendous voltages on the system which may find an outlet into the transformer. Analogously concentrated choke coils may also be detrimental in the case of great variations in currents. Defective governors of prime movers, variations in speed and voltage, high winds which bring line wires on poorly constructed transmission systems in oscillation, improperly installed protective apparatus, surges of all kinds in connection with concentrated condensers as described above are the most frequent sources of breakdowns of transformers. Therefore before installing a transformer particularly on a high voltage long distance transmission system everything ought to be reviewed from the point of generation of the energy to the point of distribution.

As to the paper on " Dissipation of heat from self cooled oil filled transformer tanks ", again I do not find that broadness I looked for on this subject; although I must say that the paper presented by Messrs. Frank and Stevens is very valuable particularly for the many tests and numerical results given: In self-cooling transformers we find a great disadvantage results from the fact that the surface of the tank is not uniformly efficient. The useful surface is almost entirely the upper one; the lower portion depending of course on the proportions of the tank, is quite useless. Before we start to adopt various artificial means for increasing the radiating surface of the tank, we should first take advantage of the surface we already have, that is, make it as nearly uniform in efficiency as possible. There is one transformer tank that meets this requirement, this is the one with the external return pipe connections between top and bottom. This tank does not represent a novel idea; about eight years ago the Stanley Electric and Manufacturing Company—Mr. Chesney who is present will probably remember—had some transformer tanks in the shop of exactly that type, this type of tank was abandoned, however, on account of the excessive cost,

Digitized by Google

and the difficulty at that time in making the welding between the coil and the tank.

In comparison with the European practice it ought to be pointed out that European transformer designers and makers are far ahead in making self-cooling transformers and tanks, and it is not unusual that capacities as high as 3,000 kw., or over are made for self-cooling purposes. One reason for this may be that the European standard for the rise of temperature is 20 to 25 degrees higher than the American standard. I personally think that our temperature limitations are too low, particularly in view of the great improvements made in insulating materials during recent years. I think it would be absolutely safe to allow a temperature rise even as high as 60 degrees instead of 40 degrees, even in the over-heated power station.

E. G. Reed: Mr. Pikler has just made the statement that the European practice in regard to self-cooling transformers is superior to that in this country, referring to the size of units which can be cooled in this manner. The above statement should not be permitted to go unchallenged, as we are to-day successfully building in this country, transformers of this type up to as high as 3000 kv-a. capacity. The method of cooling employed is to provide oil tubes external to the transformer case through which the hot oil flows, being cooled in passing. This is a distinct advance in the art of transformer design. Such self-cooled units find their use, for example, in isolated substations where water for cooling is very difficult to secure and where it is desirable to dispense with an attendant.

Just a word in regard to Mr. Allen's paper: It seems to me that the most important point in this paper is the suggestion of the standardization in the method of calculating regulation on the basis of not taking into account the exciting current. If this method is correct, and I think it is, as it lines up with the Institutes' definition of regulation it should be generally adopted.

Louis F. Blume: Before regulation was defined by the American Institute of Electrical Engineers, it was proper to include exciting current in its calculation for transformers, because then by regulation, was understood the total drop at full load in the transformer from primary applied to secondary terminal voltage. When the Institute defined regulation as the difference between no load and full load primary voltage the consideration of exciting current became negligible. Thus, as Mr. Allen points out, the only influence of exciting current upon regulation lies in the fact that at no load it is greater than at full load. This difference, however, being so very small, is only of theoretical interest.

E. A. Wagner: The paper by Mr. Allen is typical in showing that the transformer engineer does do things accurately. Our worthy President intimated that transformer engineers did not get very close in their calculations, but rather guessed at them. Mr. Allen shows several formulae for the calculation of regula-

Digitized by Google

tion, and in these several formulae he works out to hundredths of one per cent. I think it is a matter of choice, no matter which formula you take, and I know that there is considerable discussion at times as to the method of calculating the regulation and working it down to very fine quantities, and I believe it is within the province of the Institute to make a recommendation as to some definite formula, so that in the case of a discussion between a consulting engineer and a manufacturer as to the method of calculating the regulation, there is something to refer back to.

It may be true that the formulae would be subject to such discrepancies as stray exciting current or magnetizing current might produce—you might want to segregate them—but I do not think that has any direct bearing on the matter, and I want to make a recommendation that this matter of having some recommended formulae for calculating regulation be taken up by the Standardization Committee.

In regard to Dr. Steinmetz's paper, which I did not discuss previously, would state that I had occasion a number of years ago to see an actual demonstration of the forces or stresses which followed from a short circuit. It happened at Niagara Falls, and was a case of 200 kw. transformer subjected to short circuit, and it showed that the busbar winding, which was about one-half in. by two in. was strained and actually forced and distorted out of place, and at the same time, due to the same causes, the cables in the alley running from the power house were thrown off the rack—that was an actual demonstration and showed at that time that these stresses did take place.

In regard to the paper by Messrs. Frank and Stephens, on the dissipation of heat from self-cooled oil-filled transformer tanks, my experience is in accordance with theirs. I think you will obtain about 50 per cent, make the figure a constant of 50 per cent, less watts per square inch, with a corrugated sheet steel tank than with a plain cast iron tank, and I have tried to follow that out carefully, and find that the practice agrees very closely with their curves. I think that the tendency to run to very deep narrow slots will give us dead air pockets, and believe the best results will be obtained by slots or corrugations having ratios of a depth not more than twice the opening. I have not made any attempt to calculate this and arrive at a mathematical conclusion, but as a matter of practice find that the above general rule gives the best results. I do not think that good results will be obtained from the boiler tube tank, because I have tried schemes of pumping hot oil into the bottom of the tank, and *vice versa*, taking cold oil from the bottom, and circulating it from the top, so that the surface of the tank reaches the same temperature throughout—under these conditions, the lowering of temperature with a transformer having a 40 degree rise without the circulation, my tests showed we gained one or two degrees lower rise which is not enough to warrant the additional complications which this system involves.

Digitized by Google

C. A. Adams: Referring to sketch H of Mr. Green's paper, it may be of interest to show why there must be a 3rd harmonic in the transformer flux and induced e.m.f., with three-wire star connected primaries, and secondaries on open circuit.

It has often been shown that a sinusoidal flux in a closed iron magnetic circuit such as that of the ordinary transformer, requires a magnetizing current with a considerable 3rd and a lesser fifth harmonic. But a third harmonic current cannot flow in a three-wire, three-phase, star connected system, since the third harmonics in the three wires are in phase when counted positive in the same direction along the line, and would therefore be all flowing towards the star neutral at the same instant, which is obviously impossible without a neutral return wire.

Assume the secondaries on open circuit, and neglect the fifth and any higher harmonics. The currents in the three trans-

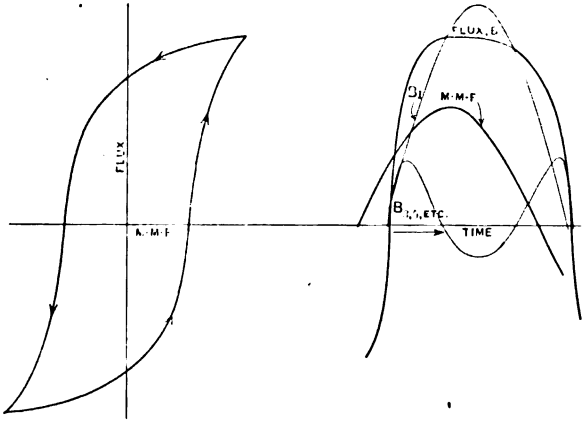


FIG. 1

former primaries will then be sinusoidal. Neglecting eddy currents, the relation between the m.m.f. and the flux is given by the hysteresis loop of Fig. 1. The sinusoidal magnetizing current or m.m.f. is plotted against time in Fig. 1. In both curves, time is indicated by the arrow-heads. The flux-time curve, derived in an obvious manner from the hysteresis loop and the m.m.f. time curve, is curve B of Fig. 1. The fundamental of the flux curve is shown in curve B, and the residual or higher harmonics in curve $B_{3,\,5,\,\text{etc.}}$ From this it is clear that there is very prominent third harmonic in the flux curve, which increases with the maximum density.

Thus on open secondary circuit, there is a pronounced third harmonic in the flux and therefore in the primary and secondary e.m.fs. It is obvious that these third harmonic e.m.fs. in the primary phase or star e.m.fs., do not affect the line e.m.f., the

Digitized by Google

wave-shape of which is determined by the supply alternator. (The two third harmonic e.m.fs. connected in series between any two primary lines are 60 degrees apart in fundamental degrees, when counted positive from line to line through the star neutral, and therefore 180 degrees apart in third harmonic degrees. They thus neutralize each other and do not appear in the line e.m.f., but merely cause a rotation of the star neutral point).

If now the secondaries be closed, either in simple delta or diametrally to a six-phase converter as indicated in Mr. Green's sketch H, the third harmonic, unless exactly neutralized by some third harmonic dynamic e.m.fs. in the converter, will produce third harmonic currents in the secondaries, the m.m.f. of which will tend to oppose their cause, namely the third harmonic fluxes in the transformer cores, *i.e.*, these third harmonic currents in the secondaries will act as exciting currents, will tend to supply the primary deficiency in this respect, and to restore the flux to the sinusoidal form. This restoration will obviously take place up to the point where the third harmonic secondary e.m.fs. are just sufficient to drive the necessary third harmonic exciting currents through the local (internal or leakage) impedances of the secondaries, and of the converter. As these third harmonic e.m.fs. are very small, the flux will be practically sinusoidal when the secondaries are connected as in sketch H.

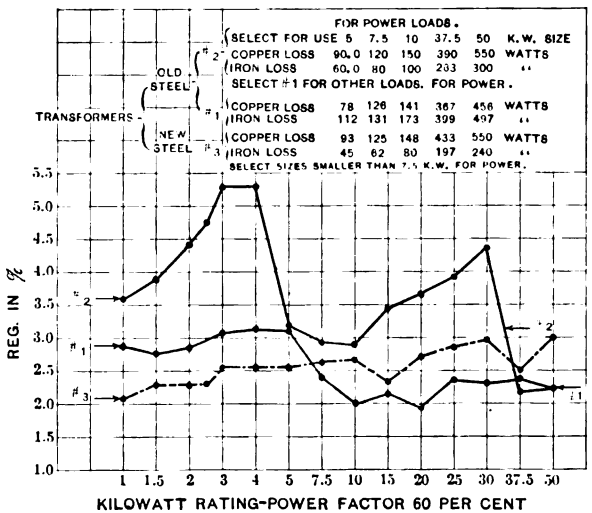
It has often been stated that the design of electrical machinery is an *art* rather than a *science*, and while there was doubtless much of truth in the statement when it was made, the application of scientific methods to a rapidly increasing number of design problems is bringing about a condition not accurately described by the above mentioned statement. As one much interested in this particular evolution, I wish to congratulate Mr. Weed on his paper, which is a step in the right direction. Of all the problems connected with the design of electrical machinery, none is at present handled in a more crude and superficial manner than the very vital problem of temperature rise. To be sure, from the standpoint of scientific accuracy, the problem is hopelessly complex, but there is much room for improvement before we begin to approach that ideal, and every step means more rational and more economical designs.

A. E. Walden (by letter): Mr. C. E. Allen's paper on "The Regulation of Distributing Transformers" is very interesting, and is in line with the method the writer has been employing for over eight years for selecting transformers for power service. The small transformers were tested with actual load, both with lamps and choke coils, obtaining actual drop directly. The manufacturers' claimed regulation is shown in the chart for three types of transformers, two using the old iron or steel, and one the new steel, and the method of selecting to get the best regulation. Actual tests taken have given better regulation than claimed by most manufacturers.

Digitized by Google

Mr. Allen's paper does not bring out very clearly the resultant loss in feeders due to poor regulation, with consequent voltage and power increase at the generating station, and the increased power required at exciter, due to lower power factor in the motors or transforming devices. In the operation of generating station and the distribution system of to-day, considering the size, the condition of low power factor deserves more attention that it has heretofore been given.

In a large distribution system at low power factor, such as is usually found with induction motors, the feeder loss with an increased drop of three or four per cent in transformers will be found to be considerable in the aggregate. In a generating station of 8,000 h.p., which the writer inspected recently, the power factor was below 70 per cent during the day, due to the


FOR POWER LOADS.
SELECT FOR USE 5 7.5 10 37.5 50 K.W. SIZE
#2 COPPER LOSS 90.0 120 150 390 550 WATTS
IRON LOSS 60.0 80 100 203 300 "
OLD STEEL
SELECT #1 FOR OTHER LOADS. FOR POWER.
#1 COPPER LOSS 78 126 141 367 456 WATTS
IRON LOSS 112 131 173 399 497 "
TRANSFORMERS
NEW STEEL #3 COPPER LOSS 93 125 148 433 550 WATTS
IRON LOSS 45 62 80 197 240 "
SELECT SIZES SMALLER THAN 7.5 K.W. FOR POWER.
REG. IN %
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
#2
#1
#3
1 1.5 2 3 4 5 7.5 10 15 20 25 30 37.5 50
KILOWATT RATING-POWER FACTOR 60 PER CENT

fact that the load was nearly all motors. This will increase this loss considerably over iron loss.

It should be noted, further, however, that the regulation of transformers tends to improve slightly with power factors below 60 per cent.

Will Mr. Allen kindly explain what the increases in cross-section of the cores would be, also increase in weight per cent, to improve the regulation to that shown by curve No. 1. Also approximately what would be the increase in transformer cost if this was done, or could be done without changing the number of turns of the copper?

Ralph D. Mershon: I am sorry I have not had an opportunity to study these papers. I am especially interested in the paper by Mr. Weed and in that by Messrs. Frank and Stephens,

Digitized by Google

not only in their bearing upon transformer design but also in connection with other engineering work where almost exactly similar problems arise relative to cooling. There does not seem to be much published data applying to this problem, and in some cases where I have required data I have been helped out by information furnished by some of my friends engaged in transformer design. But the information they could furnish was not nearly as comprehensive as would be generally desirable.

Figs. 5 and 7 of the paper by Messrs. Frank and Stephens show corrugations of such form that the section of the air space within the corrugation is greater than the corresponding oil space. I should like to ask the authors whether they have arrived at a method of determining the relation between these sections for the best result and if so what that method is.

There is another feature of the problem somewhat similar to that of the relation between the sections of the air and oil spaces in the corrugations. That is the best relation between the areas of tank surface exposed to air and oil respectively. Suppose we have a cast iron tank, for instance, having ribs on the inside and ribs on the outside. We may make the ribs on the inside and outside of different depths so that, within limits, we may vary the relation between the area of the tank in contact with the oil and the area in contact with the air. Now it would seem to me that the temperature drop to transfer a given amount of heat from the oil to a given area of tank surface would be less than that required to transfer the same amount of heat from the same area of tank surface to the air and that, therefore, less area would be required on the oil side than on the air side. It would be interesting if the authors could give us data bearing upon this point.

FIG. 1

It is not necessary to have a cast iron tank in order to control the ratio between the inside and outside areas. It can be done in a corrugated tank by collapsing some of the corrugations as in Fig. 1 and at the same time the relative sections of the spaces included in the corrugations can be controlled as indicated in the paper.

C. W. Stone: I have one or two questions in mind that I would like to ask—one is in relation to Mr. Allen' spaper. Fig. 9 shows a transformer which he calls a distributed shell type transformer, and Fig. 12 shows a core type of transformer. I do not see the difference. I wonder how he got at the name distributed shell type transformer. Apparently they are both core type. I think Mr. Allen could have brought out more prominently the increased cost of the transformer, and that bears out the point Dr. Steinmetz referred to, that the customer forces the price of the transformer down. If he has not done it, the manufacturers competing for the business have done it, which amounts to the same thing.

Mr. Pikler spoke of the breaking down of the transformer oc-

Digitized by Google

curring inside the transformer, in other places than the end turns, and he suggested this matter should be investigated. It has been investigated by the oscillograph with interesting results which will be brought out later in another paper.

I notice a point in Mr. Green's paper which I think is particularly interesting to all designing engineers as well as operating engineers, in referring to the percentage of puncture between high-tension and low-tension windings, or between the windings and laminations, as being negligible, as compared with the percentage of punctures between turns. That is based on years of experience after many investigations of burn-outs of transformers I do not think it is often given consideration.

Another point that Mr. Green makes is one that operating engineers overlook—they seem to think, if they put a lightning arrester on the line, they are free from trouble, and that if the transformer breaks down it is due to a defect in the transformer. I want to point out that the best type of lightning arrester that can be conceived will not protect the transformer, particularly if they are switched on the high-tension side. There will be internal surges which will break the transformers down, regardless of the lightning arrester. Put on all the lightning arresters you can get and then put on some more, and it will protect you from surges outside, but will not save the transformers. You must provide proper switch transformers, and particularly avoid switch transformers on the high-tension side or else you will have a breakdown.

Another point which Mr. Green makes is the question of external reactance. I am a great believer in external reactance. I am also a believer in internal reactance. I think it is a good thing to have, the more the better. I think as the systems grow larger and larger there is less need for what is called good regulation. The diversity factor which is coming into our central station work to-day means that our transformers are loaded a greater proportion of the time—consequently there is less need for the best regulation; on the other hand, as our diversity factor does come into the operation of our systems, our systems become larger and there is a greater need for reactance. Reactance in the transformer itself does a certain amount of good; reactance external to the transformer does still more good. I think that is also true in regard to generators. And I think it is a subject which should be considered in all large stations and provision should be made for the installation of external resistance, if not at the time of the installation of the transformers, at some later time.

I think there is something in Mr. Wilson's suggestion, and I would suggest that the Standards Committee take up the point, and that is the question of the temperature rise of transformers, particularly water-cooled transformers—should they be based on the air test, or should they be based on the water test. I think these two factors are important and should be considered, and they are not now considered in the Institute rules.

Digitized by Google

E. F. Alexanderson: In the design of any electric machine which is cooled by an effective system of forced ventilation the greatest problem is to predetermine the temperature gradient between the conductors and the ventilated surfaces. After the heat has been carried to a metal surface it can easily be carried off by the air. As an illustration, I wish to mention a convenient method to determine the heat radiation in machines cooled by air holes running crosswise through the laminations of the core. As result of test of various machines the watts per square inch radiated on the duct can be expressed:

$$\text{Watts per square inch} = 1 + \frac{\text{velocity of air}}{1000}$$

The velocity is expressed in ft. per min. based on 75 degrees rise of the conductors and a temperature rise of 35 degrees to 40 degrees including incoming and outgoing air. The formula is, of course, only a thumb rule, but I wish to point out the magnitude of the quantity. If the velocity of the air is 2000 ft. per min. the radiation is 3 watts per square inch or 10 to 20 times as great as the figures mentioned for exposed coils in transformer design. This indicates that the largest temperature drop is in the insulation.

There is another circumstance that points to some peculiarities of the heat conductivity of insulation. The behavior of some transformers indicate that the temperature rise of a ventilated coil increases faster than the watts per sq. in. In other words, the heat conductivity changes considerably with the temperature. In view of this the question would seem pertinent, what is the heat conductivity of the various insulating materials, and I believe it would be of benefit for machine design in general if rules for determining the heat conductivity of insulation materials received as much attention by the Institute as similar data for dielectric strength.

Henry A. Pikler: I want to refer, in a few words, to the remarks made by Mr. Stone—he pointed out two things, one is the switching of the transformers on the high tension line; he desires to have some method devised and adopted whereby this could be avoided; in other words, he wants to see some rules introduced and accepted by the customer or the operator that transformers should not be thrown directly in the high tension line; the other thing that he pointed out, is that the introduction of reactance outside or inside is desirable. It is very interesting to note how intimate the relations between these things are. As to the first point, I do not think that is feasible. I cannot imagine any way whereby we could avoid throwing the transformer on the high tension line directly, except by shutting down the power entirely, if this transformer be the first transformer at that point. If we insert reactances in the circuit—let us say,

Digitized by Google

more generally speaking, a series impedance, the result will be the distortion of the sine wave generated by the generator, at the terminals of the transformer.* This, of course, is quite serious, because we want to avoid the higher harmonics. With the introduction of the reactance, particularly at the moment of throwing on a transformer on the line, we will introduce these higher harmonics in a greater measure, than if we do not use the series reactance outside of the transformer circuit. And if the series reactance does not cause this then this proves its ineffectiveness for the purpose it was intended for.

C. P. Steinmetz: Regarding the remark made by Mr. Stone on the undesirability of high tension switching, I desire to endorse it, and still more particularly to draw attention to one interesting feature. We very often have done, and still occasionally do, things which we should not do, but we do them because we do not know any better, and as result, apparatus occasionally broken down by some mysterious phenomenon,

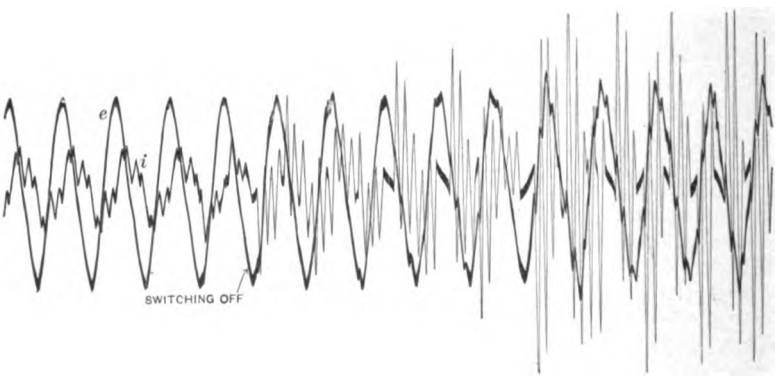


FIG. 1

which would not have been mysterious but for lack of knowledge. One of these things is the high tension switching. It has to be done, and will be done, but the less we do it the better it will be. We never realized this until we had the oscillograph on the high tension switch on very high voltage, long distance lines. It is easy to specify and say you must do it—certainly some time you may do it—but after looking at the oscillogram you will realize that the more we avoid high tension switching, the better it will be for the apparatus. In Fig. 1 is shown the oscillogram of a cumulative oscillation, resulting from high tension switching. Not shown in this oscillogram is the momentary and extremely local very high frequency traveling wave starting the oscillation, which is estimated of a frequency of two million cycles, and measured by its disruptive effects.

*H. A. Pikler, effect of series resistance in the primary circuit of a transformer. *Electrical World and Engineer*, 1903, p. 218.

Digitized by Google

Now, in regard to reactance, the place for high reactance is not in the high voltage line, where the high tension switch is objectionable. When you have a line in which you have to go to 100,000 volts, you are fairly certain there will be a voltage drop of ten per cent or more, whether the transformer has a high or low reactance, because the power which can flow through the transformer is limited. It is in those systems where the power is unlimited and the drop is negligible, a different class of systems, where the destructive effects of low reactance have been conspicuous.

When you speak of reactance, however, one thing must not be overlooked. If you say, a four or six per cent reactance is desirable for safety, that means you must have the reactance when you need it. It is wrong to put in an iron-clad reactive coil, which gives four per cent reactance at full load current, and when you get 25 times full load current, the reactance disappears by magnetic saturation, and wave shape distortion comes in. This has not been mentioned, because it is obvious. If you put reactance in to limit the short circuit current, the reactance must be there under short circuit, and this excludes the use of iron. In a transformer the maximum flux on short circuit is only full voltage flux, and magnetic saturation at short circuit thus cannot occur in a transformer, but in an additional reactance, it may, if iron is used, and that mistake has been made more than once, to use iron in power limiting reactances, with the obvious result, that the reactance was not there when you wanted it, and so did not serve the purpose for which it was designed.

J. M. Weed: Mr. Alexanderson's equation for cooling with forced circulation of air is represented by a straight line curve between watts and air velocity, cutting the axis for watts at one watt per sq. in. This line, no doubt, approximates the actual physical conditions for the high air velocities occurring in machines. For low velocities such as we find in the air which cools the self-cooled transformer the actual curve will be found to droop from the straight line and to cut the axis not far from the zero point. A similar condition exists with reference to the action of the oil in cooling transformer coils. This does not indicate that the largest temperature drop is in the insulation, as was suggested by Mr. Alexanderson, but rather that a very large temperature drop exists from the surface of the coil to the oil or from the surface of the tank to the air with the slow velocities occurring with natural circulation. This temperature drop at the surface is very much reduced by means of increased velocities obtained by artificial circulation. Some consideration was given to this matter in my paper and some also to the question of heat conductivity of insulating materials.

I would say that there must be something wrong with the transformer tests which showed a temperature rise increasing more rapidly than the watts per sq. in. producing this rise, since I have found from a large number of tests that there is a distinct

Digitized by Google

tendency in the other direction. I have not found any definite variation in the thermal resistance of solid insulating materials, but do find a reduction of the equivalent thermal resistance at the surface of the coil, or the tank, as the watts increase, which I have attributed to the increased velocity which is automatically produced in the cooling fluid.

Mr. Mershon's questions about corrugations, and relative areas of surfaces exposed to oil and air, are partially answered in the last few paragraphs of my paper. To be more explicit, without being too exact, I would say that the space on the air side of the corrugations may, to advantage, be made from two or three times as great as that on the oil side. The width of the oil space may be reduced to from one inch to one-half inch, depending upon the height of the tank, without causing a serious drop in the oil temperature while passing downward from the top to the bottom of the tank. The width of the air space should vary from one to two and one-half inches, depending upon the height of the tank and the depth of the corrugations. If this space is too large the heat does not sufficiently penetrate the enclosed air, and part of the space is wasted, while if it is too small the friction to the passage of the air is too great, and its acceleration is not sufficient to draw in enough new air to keep its temperature down to a point which is properly effective in absorbing heat from the surface of the tank.

Within limits the higher the tank the wider the corrugations should be, both inside and outside, and the deeper the corrugations the wider they should be.

It is instructive, when considering the size of the corrugations, to reflect that with a given ratio of pitch to depth of corrugation, and given perimeter, the area of the tank surface will be the same whatever the size of the corrugation. The volumes of air and oil brought within the corrugations, and thus brought within effective range of the surface, will depend however upon the size of the corrugations. If the reduction in size is carried to the limit, the conditions of cooling approach those of a plain surface, which gives the minimum cooling for the given perimeter, although we have not reduced the area of our corrugated surface. Thus, within limits, the larger the corrugations, the more effective the surface.

As to the relative amounts of surface which should be exposed to air and oil respectively, if there were just so much total surface which could be distributed at will between the oil and the air this question would be more logical. With the cast iron tank with ribs we can make either surface what we wish, regardless of the other. Though the ribs may be said to be less important on the side toward the oil than on the side toward the air, since the temperature drop from the tank to air is normally greater than that from the oil to the tank, yet they are valuable on both sides. Because we have ribs on the outside surface is no reason why we should not also have ribs on the inside surface.

Digitized by Google

With the corrugated surfaces, keeping the perimeter of the tank the same, the external surface will be increased somewhat by closing or collapsing the spaces on the oil side, keeping the width of external spaces the same, on account of the increased number of corrugations.

By closing all the internal spaces we might obtain an increase of about 50 per cent in external surface but this would be accompanied by a decrease of about 75 per cent in the internal surface. Assuming that the drop from the oil to the tank, before the corrugations are closed, is six deg., and that the drop from the tank to air is 30 deg., if each of these drops is proportional to the watts per sq. in. on the respective surfaces (which is not strictly correct) the respective drops after closing the corrugations will be 20 deg. external and 24 deg. internal. The sum of the two drops is now 44 deg. as compared with 36 deg. before the corrugations were closed. This calculation is rough and probably gives results somewhat exaggerated but it correctly illustrates the tendency.

Mr. Mershon may object that he did not contemplate closing all of the corrugations, but each corrugation must be considered to a certain extent independently, since the heat which would be conducted through the thin sheet steel tank from the corrugation which is not closed to the one which is closed would be much smaller than at first imagined. Moreover, the reduction in the temperature drop from the tank to the air will be less than would be expected from the amount of increase in the surface, since, not being adjacent to the hot oil, the tank temperature will be somewhat reduced toward the tips of the closed corrugation.

In addition to the above I should like also to offer some remarks on Mr. Pikler's discussion of Mr. Green's paper as follows:

Mr. Pickler's statements regarding mechanical forces and regulation in his discussion of Mr. Green's paper seemed to give a wrong impression. It is the natural tendency of the resistance element of regulation to be reduced with increased capacity, but not of the reactance element. Certainly the reactance in ohms would decrease but the per cent reactance, or reactance volts, tends to increase to the extent that for a given per cent reactance it becomes necessary to break the windings of a large transformer up into a larger number of groups than those of a small one. It is certainly true moreover, that the mechanical forces under short circuit conditions in any given transformer will be reduced by increasing its reactance. It is true, in fact, that if all dimensions and parts of the transformer including the coil supports are increased in equal proportion, all sizes of transformer will be equally safe, except for the affect of the variation in the space factor of the windings which is unfavorable for the larger sizes.

In order to be equally safe, therefore, the larger sizes must be protected by a greater than normal increase, either in the strength of the coil supports or else in the per cent reactance.

Digitized by Google

R. W. Atkinson (by letter): While the writer wishes to confirm certain of the points brought up by the author, he wishes to take exception to certain of the others. He is glad to see presented before the Institute, the formulae for the calculation of regulation and particularly those regarding the effect of magnetizing current, and would refer to the work done by the Bureau of Standards. The question was taken up very carefully by them, both theoretically and experimentally. They arrived at the same conclusions given by the author. Their results are published in their Bulletin No. 2, Vol. 6. However, the writer does not agree that the cost to the central station of regulation is ordinarily dependent upon the selling price of the power. He also wishes to comment slightly upon the curves in Figs. 4, 5 and 6. It is intended only to mention the above points with a very brief analysis of the reasons for the conclusions.

It is merely desired to call closer attention to the Figs. 4, 5 and 6. The casual reader might draw somewhat erroneous conclusions. In Fig. 5 it is desired to point out that with a purely lighting load where the effect of regulation is most marked, the influence of reactance upon regulation is least noticeable. It is suggested that the various transformers represented in Fig. 6 by curves 1 to 7, could scarcely be considered as having the same general dimensions. No. 7 would have $\frac{1}{4}$ the copper loss of No. 1. Obviously, this would require a very much larger and more expensive transformer unless, of course, some characteristics not mentioned are sacrificed. In case the reduction of the copper loss is at the expense of increased iron loss, the reactance would be reduced in approximately the same ratio as the copper loss. The same comment would apply to Fig. 4 but in a much less degree.

It has been frequently asserted that, on a lamp load, due to a reduction of voltage at the customer's outlet, regulation reduces the power sold to the customer and that therefore the cost to the central station is the difference between the selling price and cost price of this amount of power. Suppose this is true. We ask then why does it not pay to raise the voltage of the system and sell more power, why not do this indefinitely? It is unnecessary to analyze the reasons for not so doing. However, we know that it will pay to make the average voltage of the system approximately that which we would maintain all the time if it were not for regulation. If there is a certain voltage which it would be desirable to maintain uniformly, if possible, it would seem to scarcely require argument that if it is impossible to maintain a uniform voltage, the next best thing is to make the voltage vary *above* and *below* this desirable voltage, and as close to it as possible. The cost of regulation then lies in the effect of this variation of voltage, and regulation is costly just to the extent of the uncertainty and the variation of receiver voltage due to it.

An important effect of the irregularity of voltage is the re-

Digitized by Google

sultant variation of candle-power of the lamps of the system. In the case of carbon lamps, there is as well a variation of the color of the light. The problem then becomes quite largely one of the psychology of the customer. It is quite certain that if the variation of candle-power becomes serious enough to be offensive, it is very expensive to the lighting company, and is negligible only when not noticeable to the ordinary customer.

The most important effect of regulation is upon the life of the lamps. A lamp burning one-half the time at 109 volts and the other half of the time at 111 volts, has a shorter life than one burning steadily at 110 volts. It is possible to calculate this loss of life due to regulation very accurately from the performance curves furnished by the lamp companies. One thing of interest is that the loss of life varies approximately as the square of the regulation.

The average candle-power and efficiency are not so greatly affected. As a matter of fact, both are slightly increased under the above specific conditions of 109 volts half the time and 111 half the time, as compared with a uniform voltage of 110.

The copper loss of the transformer is so closely related to its regulation on a lighting load, that we may be pardoned for a brief reference to the cost of this copper loss. It needs merely to be mentioned that the cost of power occurring almost entirely at or near the peak, is much greater than the cost per kilowatt hour of an all day load. If this cost is the one cent per kw. hr., mentioned then perhaps the copper loss costs two cents. It is not intended here to show the amount of the difference but merely to call attention to its existence.

There are a great many factors which may influence this problem including those mentioned by the author. Some others are: regulation of the secondary circuit between the transformer and the customer's outlet; the possibility of the voltage of the primary being raised at times of general heavy load on the feeder. The first may be of considerable importance and complicate the problem accordingly. It is sometimes practicable to reduce materially the effects of bad regulation by consideration of the latter.

The writer has attempted to show in a general way that the cost to the central station of regulation is affected not by the selling price of the power, but by the effect upon the life and the candle-power of the lamp and upon the resulting satisfaction of the customer. Where regulation is important, that part due to reactance can always be kept low with less expense than that part due to resistance. The problem of the cost of regulation is an important part of the larger one, that of the cost of the transformer losses, and is a subject which is of great interest to both the designing engineer and to the operating engineer.

C. E. Allen: In regard to Mr. Walden's question regarding the increase in cross section of the cores, it is not clear as to just which figure is referred to, but at any rate the cross section of the core would vary, depending upon its construction. This

Digitized by Google

would be also true of the weight. As to the increase in cost of the transformer I have no figures at hand that are sufficiently accurate to answer this question, but I might add that the weight of copper would increase directly as the increase in the mean length of turn due to the larger cross section, and there would be also an increase in the weight of the copper due to the increase of $\frac{A}{L}$, which represents the leakage path of the flux, in determining the regulation. It would not be an economical design to improve the regulation by increasing the cross section and allowing the number of turns to remain the same.

In replying to Mr. R. W. Atkinson's discussion, the writer appreciates that there is nothing original brought out in the paper, as all the formulæ brought in have been worked out by Dr. Bedell of Cornell University, Mr. Fortesque and various others. The writer has simply made a summation of correlated facts, with a view of showing certain points, which he hoped would be sufficient to justify the Institute adopting a standard method for determining the regulation.

As to the conclusions that might be drawn from Figs. 4, 5 and 6, this depends altogether upon the experience of the reader. The paper is only intended for those familiar with the subject. As to the variation in the power delivered due to changes in regulation, I have been over this subject with various central station engineers, whom I believe represent the leading men in their respective lines, and in all cases they have figured the loss due to poor regulation at the selling price less the cost of delivering the energy to the transformers. Mr. Atkinson asks why it would not pay to increase the voltage indefinitely. While this is no doubt obvious to many, I will answer by stating that there is the question of satisfactory service, which must be considered. Mr. Atkinson has based his statements entirely upon the assumption that only an incandescent lamp load was used. As a matter of fact the importance of the paper at this time is due to the increased day load made up of heating apparatus, etc., the nature of which is similar to that of an incandescent lamp, but where the question of renewals does not enter. On account of this increasing day load, the regulation and copper loss have both become of more importance than previously. At one time the iron loss of a transformer was considered to have a relative value six times that of the copper. This was assuming that full load existed only four hours of the day. To-day the same difference does not exist and, therefore, the value of the regulation and copper loss have been increased.

In taking up this subject the author has not dealt with its influence on induction motors; which is quite as important as the other loads. This is appreciated by central stations serving industrial districts and is brought out in Mr. A. E. Walden's discussion.

Digitized by Google

DISCUSSION ON "MECHANICAL FORCES IN MAGNETIC FIELDS", PITTSFIELD, FEBRUARY 15, 1911. (SEE PROCEEDINGS FOR DECEMBER, 1910.)

(Subject to final revision for the Transactions.)

A. S. McAllister: The author has called attention to the error involved in dividing the difference in energies in two positions of a solenoid plunger by the distance it moved to determine the force acting upon the solenoid. He has also intimated, without stating directly, the cause for that error. The energy in the magnetic field is expressed as $\frac{1}{2} L I^2$. It is somewhat analagous, not to potential energy, but to kinetic energy, that is, not to $f l$, but to $\frac{1}{2} M V^2$. In dealing with potential energies, the energy in one position may be subtracted from the energy in another position, and the difference divided by the distance between the two positions then gives the force. However, in the case of the solenoid the two energies are the kinetic energy under one condition and the kinetic energy under another condition, and the movement of the plunger is merely an incident to the change in the condition. The energy in the magnetic field cannot be defined as $\frac{1}{2} L I^2$ unless L is constant, as is true for the air circuit, but is not true for the iron circuit. Therefore, the equation given by Dr. Steinmetz cannot be applied directly when iron is in the circuit; which means that the equations, if used, become very complicated. As a matter of fact it is preferable not to use the equation, but as the author indicates, resort to graphical or similar methods for determining the energies in the two positions or the change in the energy with the change in position.

G. Faccioli: The value of mechanical forces which act on transformers under short circuit conditions is enormous, as pointed out by Dr. Steinmetz. So the transformer which has enjoyed the reputation of having no movable parts presents to the designer a difficult problem, that is the problem of keeping the windings in place when a short circuit occurs.

This purpose may be accomplished by adopting for the windings an exceptionally strong mechanical structure and, in certain instances, by distributing uniformly the leakage flux through the width of the leakage path thereby distributing the mechanical forces evenly throughout the leakage area.

But on account of the magnitude of these forces it seems necessary to improve the conditions by reducing as much as possible the forces themselves.

These forces are proportional to the leakage flux and to the current.

The leakage flux is proportional to the applied e.m.f. and if we assume that the power behind a transformer is unlimited and therefore the voltage will be maintained at its full value under all conditions, it is impossible to reduce the value of the leakage flux. We can, however, reduce the current by increasing the reactance of the transformer.

Digitized by Google

For instance, if a transformer has two per cent reactance, this means that two per cent of the full voltage will send full load current through the apparatus with its secondary short circuited. If we apply full voltage to the transformer 50 times full load current will flow.

We then have, for two per cent reactance, flux one, short circuit current fifty, force fifty times one equals fifty.

If we double the reactance and make it four per cent, then the short circuit current at full voltage is twenty-five times full load current or one-half the value with two per cent reactance. The flux is one as before, the short circuit current is 25, therefore the force is 25 times one equals 25 or one-half what it was in the preceding case.

By increasing the reactance of a transformer we decrease in inverse proportion the mechanical forces on the windings.

If the reactance is not all in the transformer as inherent reactance but is divided in two parts, one inherent in the transformer and the other external to the transformer, the conditions are somewhat different.

Let us assume two per cent reactance in the transformer and two per cent outside reactance, then the total reactance of the circuit is four per cent and the short circuit current is 25 times normal load current. This short circuit current flowing through the external reactance causes a drop of e.m.f. equal to two per cent times 25, equals fifty per cent normal electromotive force.

It follows that we apply to the transformer one-half only of the total voltage and that the leakage flux is reduced to one-half its full value. The force is then equal to one-half times 25 equals $12\frac{1}{2}$ as against 25 which was the value of the force when the four per cent reactance was all inherent reactance of the transformer.

It appears that by judicious use of reactance we may be able to improve short circuit conditions and to reduce the mechanical forces to a considerable extent.

Formerly in the days of small units and limited power the factor which controlled the amount of reactance in the transformer was the regulation. Now, with large units and enormous powers, another point of view is added, and that is the ability of a transformer to withstand short circuit.

As it is generally the case the design of the transformer must be a compromise, because while on one hand we should use low reactance to secure good regulation, on the other hand we need high reactance to limit the value of the short circuit current.

In large power transformers the ability to withstand short circuits is far more important to modern engineers than good regulation.

Cassius M. Davis: I wish to offer an explanation of the operation of a solenoid when used to actuate an oil switch by means of a toggle mechanism. The plunger of the solenoid acts on the middle joint of the toggle, moving it until the two arms are brought a little beyond the point where they are in the same straight line.

Digitized by Google

The electrical operation may be outlined by reference to Fig. 1. The plunger in its initial position gives the solenoid the inductance L_1, and the current, starting at time t_0, would rise along the transient curve i_1. After time t_1 the current has risen to produce sufficient flux to start the plunger and it begins to close the toggle. In doing so the inductance of the solenoid increases, and an increase of inductance means a decrease in the rate at which the current rises in the solenoid. Thus at t_1 the current begins to rise along another transient curve indicated by i_2. At t_2 the arms of the toggle have come into line which suddenly releases the load and the joint breaks back to lock the switch mechanism; the plunger then suddenly jumps to its final position reaching it at t_3, and with it the inductance increases from L_2 to L_3, which may mean an actual decrease of

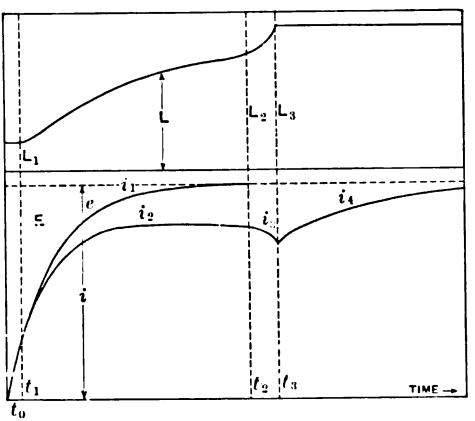


FIG. 1

current, indicated by i_3. From t_3 the current rises along a curve i_4 determined by L_3 and the current at time t_3.

The power at any instant is the product of the current and the induced voltage at that instant, and the induced voltage is proportional to the ordinates, e, above the curve; hence the energy consumed by the solenoid is the area product above and below the curve. Now the area above the curve is constant since the total voltage induced, E, is proportional to the total number of lines of force cut which is constant. Thus the work done by the electrical energy supplied depends only on the area under the curve, and hence the longer time the solenoid acts the more work it can do. The condition for maximum work may be represented by Fig. 2, where the current rises to nearly its final value before the plunger starts, which then moves in such a manner as to keep the current constant until the end of the motion.

Digitized by Google

This diagram will serve to derive an expression for the maxi-n um work. The electrical energy consumed is

$$W = \int e\, i\, dt = i_0 \int e\, dt$$

but

$$\int e\, dt = E = \text{constant.}$$

Hence

$$W = i_0\, E = i_0\, n\, \phi\, 10^{-8} = i_0^2\, L$$

but the magnetic energy stored at the completion of the motion is

$$W_1 = \frac{i_0^2\, L}{2}$$

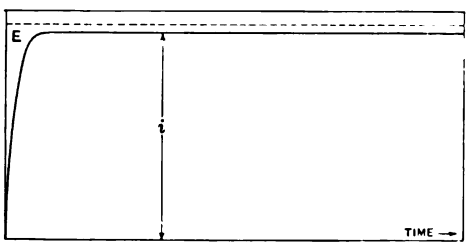


FIG. 2

Therefore the maximum mechanical work is

$$W_2 = W - W_1 = \frac{i_0^2\, L}{2}$$

which is one half of the electrical energy consumed; or the maximum efficiency of a solenoid is 50 per cent.

—— **Harper:** With particular reference to that portion of Dr. Steinmetz' paper which has to do with stresses in transformers, it will, perhaps, be interesting to present certain tests, the results of which are very gratifying indeed, and to discuss some of the peculiar conditions that are likely to exist in practice

The expression $F = \frac{810\, e_0\, i_0}{f\, l}$ g-cm., or $\frac{0.706\, e_0 i_0}{f\, l}$ in. lbs. formula (**54**) is readily verified by simple tests, performed with two similar coils, one being horizontally suspended directly over the other.

Digitized by Google

Two series of such tests were compiled some two years ago with arc light reactance coils, at Lynn and are shown here, tabulated. One set of tests shows an error of approximately $7\frac{1}{2}$ per cent, while the other gives an error of approximately $6\frac{1}{2}$ per cent.

It is seen that in both cases the calculated value is lower than the test value. This is probably due to the fact that the voltages have not been properly corrected for $I\,R$ drop.

Another series of tests were performed at Pittsfield some two months ago, the error of which is approximately $2\frac{1}{2}$ per cent. This value is well within the accuracy limits of the measuring apparatus.

The force thus determined, which may be called a horizontal force for convenience may, under certain conditions, be made up of components which are likely to be dangerous.

If, for instance, in that portion of the coils of shell type transformers which project beyond the core, the primiaries are not directly opposite the secondaries, but have the effect of being staggered as shown in Fig. a couple exists, which tends to warp the coil. The centre line of magnetic gravity of the primaries is not in the same plane as the centre line of the secondaries. Hence, the resultant centre line, or direction of the force will not be horizontal, but will exist at an angle as shown in the figure.

Any coil carrying current will have a tendency to assume a circular shape. In shell type transformers, the legs of the coil are firmly held in position by the core, the ends, however, will tend to form of themselves semi-circles.

One other point to be considered is the tendency of a coil to form of itself a cable.

It should be remembered that the intensity of leakage flux is not uniform throughout the width of the coil, but is greater at the centre of the coil (if the coil be imbedded in iron). If then, a short circuit exist, the coil will have a tendency to buckle, and should it not be sufficiently strong to overcome this tendency, and its equilibrium be disturbed, the forces of conductor upon conductor (the value of which may be determined from formula (**57**) of Dr. Steinmetz' paper) will not lie in the same plane, and hence are liable to break the insulation tapings, and pile up on each other at the point of most intense density.

F. C. Green: A few instances of the effects of electromagnetic forces that have been observed in the practice of using transformers, will be given.

Seven or eight years ago some transformers returned from a large power plant, were observed to have the ends of the outside coils flared, as shown in Fig. 1. This was among the first instances to be brought to the attention of the designing engineers. To prevent the distortion of the coils at the ends, supporting strips were arranged as shown in Fig. 1. After the adoption of this construction no more trouble was experienced

Digitized by Google

with the flaring of the ends of the coils, but as the power installations became larger and larger, it was found that under short circuit conditions, the coils were entirely collapsed and twisted. The tendency seemed to be to make cable of the vertical portions of the coil. Mr. Harper pointed out that the portions of the coil outside of the iron tend to take a circular form under short circuit. No effect of this kind has been

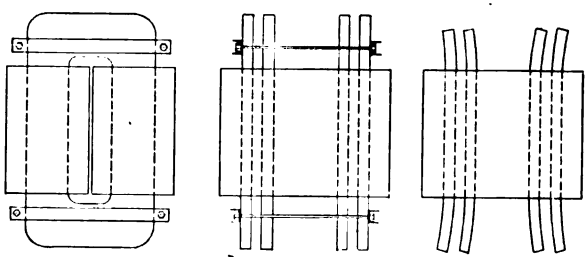


FIG. 1

noticed except at the corners of the coil. Here a number of instances of almost perfect circles of the copper conductor have been observed, the diameters of the circles being, however, from 1 in. to 2 in.

Nothing has been said about electromagnetic forces in core type transformers. The dotted lines (Fig. 2) show the position of the low tension coil and the solid lines show the position of the high tension coil. Under short circuit, according to the mathematics that have been developed, the force in this case is exerted horizontally, and there is little tendency to produce motion upward or downward. If we assume that the center of the primary coincides with the center of the secondary, then there can be no motion in the vertical direction, but it is found that considerable damage is done occasionally from the forcing of either the primary or secondary coil up into the iron. In most instances, the secondary is forced up. A better idea of the magnitude of electromagnetic forces is obtained in the destruction of core type transformers than in the destruction of the shell type, for the simple reason that while the core type coils are supposed to have their centers coincide approximately, they never do exactly, and so the force to produce vertical motion is exerted at such an angle as to make this force only a very small per-

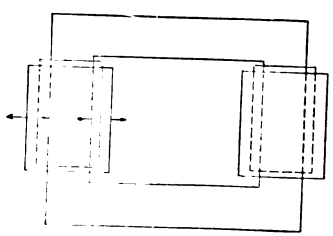


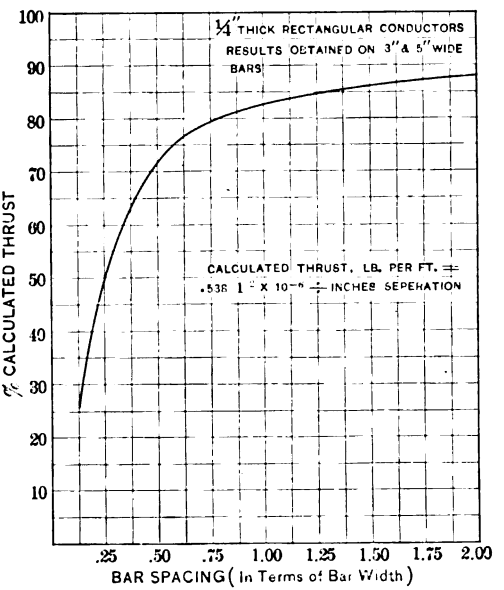
FIG. 2

FIG. 3

Digitized by Google

centage of the total force exerted between the primary and secondary. If the centers of the primary and secondary were exactly coincident the entire force would be exerted in a horizontal direction, and there would be no tendency for either coil to move vertically; but it seems that for mechanical reasons the secondary usually extends a little higher than the primary, resulting in the relation of forces indicated in Fig. 3. Of course whether the primary or secondary is forced up depends upon which one has its center line above the center line of the other.

C. J. Barrow: I wish to remark on the stresses between parallel conductors, Dr. Steinmetz considers the problem in his general solution. In this particular case it seems a little easier and more



Thrust on parallel conductors carrying current

direct to consider the stresses from the veiwpoint of the thrust on a current in a magnetic field. If we assume circular conductors and a field concentric about their centers, we can readily express the field at any point and calculate the thrust on a current in this field. The thrust on unit current (10 amperes) in a field of one line per sq. cm. is one dyne per cm. length of current acting normal to field and current. Working on this basis and converting to lbs., feet and amperes we get a formulae which exactly corresponds with that developed by Dr. Steinmetz based on the reactance of the conductors—lbs. per ft. $= 0.538\, I^2 \times 10.^{-6}$ divided by the separation of conductors centers in inches.

In the case of bus bars of rectangular section the forces are not

Digitized by Google

the same as for cylindrical conductors. The field is no longer concentric about central element, but elliptical with long axis of section as major axis of ellipse and the current acted on cannot now be approximately considered as concentrated at the center of conductor. Both considerations operate to reduce the forces exerted particularly between bars on short centers; the first by reducing the average field active, and the second by necessitating consideration of the thrust on a band of current the various elements of which are not all impelled in the same direction. In order to get a line of the corrections necessary on account of these considerations as well as to bolster up our faith in calculations of the forces present in high power bases under short circuit conditions, test determinations were made of the forces obtaining between 3 in. x $\frac{1}{4}$ in., and also 5 in. x $\frac{1}{4}$ in. bars arranged with faces parallel on various centers and at various currents. These tests made with direct currents ranging from 1000 to 8000 amperes, showed that forces varied as the square of the current and that with bars spaced on centers equal to the width of the bar about 80 per cent of the calculated forces obtained. At greater spacing larger values and at shorter spacings smaller values were found. Plotting results as per cent of calculated forces against spacing in terms of the width of bar used, the curves for 3 in. and 5 in. bars were found to coincide closely and it is felt that the curves obtained apply approximately to any width of bar. The results were obtained on bars $\frac{1}{4}$ in. thick. As bar thickness increases, cylindrical conductors are approached so with thicker bars somewhat higher results are to be expected.

Henry Pikler: In the present paper, also in some of the papers read yesterday, and in papers which will be read, there is much more said about forces in transformers than we were accustomed to hear about in the past. What is the cause of this? Nothing else but that perhaps recently more transformers broke down, due to forces which arose in them created by short circuit which occurred on the secondary side of the transformer. Why do transformers go to pieces by such short circuits? We used to have transformers of small and also very large capacities in the past; we used to have very large power stations with so called unlimited power; why is it that at present transformers are more likely to be ruined by short circuits than in the past? The answer, to my mind, is this: The art of making insulating materials has advanced rather rapidly and the properties of insulating materials were greatly improved, the mechanical construction of the transformer, however, has not kept pace with it, particularly the mechanical construction of the windings and their supports. From the very extended discussion already heard, on this subject, it seems to me that we have all received the impression that the windings of a transformer, particularly of the type of transformers which were shown here, are very weak mechanically, and that their supports are also very weak. When the insulating materials are improved, the high

Digitized by Google

and low tension windings are brought closer together, consequently, the reactance of the transformer is diminished, and the forces arising on short circuits will be greatly increased. Hence, the weakness of the mechanical construction will be more apparent. Although it is very important to have a sufficiently high reactance in the transformer windings, this idea is not new —several years ago the results of investigations were published on this subject in the *Elektrotechnische Zeitschrift.** This idea was also embodied in transformers of large size with unlimited power behind, with successful results. The main trouble, as I see it, lies in the mechanical construction: The entire mechanical construction of the large shell type transformers, coils of which were exhibited here to-day, is such that it does not admit the proper supporting of the windings and does not permit of a solid interlocking between these windings, and the windings and core.

As to the calculation of these forces as given by Dr. Steinmetz, the derivation of the formulas is elegant, and the results are simple. The question is, however, whether they apply to actual conditions. I do not think they do. Those gentlemen who stated that they made actual tests and found that the results checked up very well with the formula given, I believe did not make those tests under actual operating conditions. I wish to ask if any of these gentlemen measured the forces in a transformer on a short circuit with unlimited power behind? I hardly think they did. An agreement with the formula was found as the result of tests made under conditions as may be found in the laboratory. If you take a transformer and short circuit it on one side and then gradually apply voltage to the other end until you reach any desired current, you will find that this current, which is called the short circuit current of the transformer, is proportional to the impedance voltage of the transformer. Also the forces will be found to be in proportion with the reactance, one of the components of the transformer. But when you have a transformer on the line, and *then* suddenly apply a short circuit on the secondary side, or you short circuit first the secondary side of the transformer and then suddenly switch the transformer to the line, you will find that the short circuit current and the forces arising in the transformer will be quite different from those given in the formula. These will depend upon the magnetic conditions of the transformer at the moment of the short circuit, that is the magnetic condition of the iron core and the relative phase relations of the current in the primary and secondary winding.

The analysis of the formula alone, as obtained by Dr. Steinmetz, is not sufficient for finding a remedy that will prevent the wrecking of the transformer windings by the forces arising on short circuits. It is necessary to go back to the derivation of the formula, to the place where Dr. Steinmetz allowed the coils

*Grosze Transformatoren für Electrochemische Zwecke, by Vanizian —Jan. 24, 1909.

Digitized by Google

to move a certain distance in order to transform the potential energy into kinetic energy. Here is the salient point. The transformer must be constructed so as to preclude any such motion of the windings on short circuits.

John J. Frank: The reason the subject of stresses in alternating current transformers is of greater importance now than formerly is because ten or twelve years ago transformers were connected to lines in which the power back of them was relatively small. The recent combination of power plants into big systems gives practically an unlimited amount of power as far as small transformers are concerned. Small transformers which heretofore might have been rather weak in mechanical construction, but did stand up under short circuit conditions, are now not capable of doing it.

I do not believe that under actual operating conditions a break-down usually occurs the first time the strain is applied. A certain milling occurs in the core type as in the shell type, and it is only after repeated short circuits that the transformer fails and we get the twisting of the coils of the shell type transformer and the displacement of the coils of the core type transformer

Charles F. Scott: As remarked by the last speaker, the trouble is often not with the transformer, but with the power plant. In one case some large transformers were installed in a station of some 12,000 kw. and behaved beautifully for a number of years. They then began to break down, due to the fact that more generators had been added, and the short circuit currents were much larger. Although formulæ and diagrams are interesting, they do not give any adequate idea of what these forces are, compared with what one gains from an inspection of transformer coils which have been badly distorted. Coils of copper of large section bent around at sharp angles, and twisted up in great contortions, give an idea of a force away beyond our ordinary conceptions of the force of the magnetic field. I remember one case which I think is different from those mentioned, in which one part of a coil was peculiarly distorted. The coil was wound as a single layer of square wires about as large as one's finger—a part of the wires of the layer had been twisted and bent around in a most remarkable way, as part of the coil had slipped over on the other part. By a careful analysis of the position of the wires I found that a part of the primary coil had short circuited, and acted as a secondary in relation to the rest of the primary, setting up terrific forces within the coil itself, part acting as primary and part as secondary.

H. C. Cox: For the past eighteen months it has been the practice of the transformer testing department with which I am connected to subject all core type transformers of over 50 kw. capacity to a short-circuit test of five times rated current, applied suddenly on lowest tap connection through the make and break of an oil switch. During this period but one case (easily reme-

Digitized by Google

died by tightening coil supports) of coil displacement has been found.

Since the convention a 55 kw. transformer was subjected, out of oil, to twenty-seven times rated current without injury. Aside from heating and excessive vibration of core laminations no effect of the strain was apparent.

V. Karapetoff: Dr. Steinmetz's paper contains no literature references, nor does he give credit to previous investigators of the subject. Therefore, the following references may be of interest. His formula (**16**) has been known for at least twenty years; it can be found in the 1890 edition of Vaschy's "Traité d' Electricité et de Magnetisme", Vol. II, p. 35. For the principle upon which it is based see Maxwell's "Electricity and Magnetism", Vol. II, Art. 580.

The general theory and design of tractive electromagnets from the point of view of energy was given by Fritz Emde in his series of articles "Zur Berechnung der Elektromagnete" in *Elektrotechnik und Maschinenbau*, 1906, p. 945; also in the *Elektrotechnische Zeitschrift*, 1908, p. 817. He gives a proof of Kelvin's law that, when the currents in an electromagnetic system remain constant during a deformation of the system, the energy supplied by the sources of e.m.f. is divided equally, one half being converted into mechanical work, the other half increasing the stored magnetic energy of the system. From this law Steinmetz's equation (**16**) follows directly, because $\frac{1}{2} i_0^2 \, d\, L$ represents the increase in stored magnetic energy, and $F g d l$ is the mechanical work. Fritz Emde also proves that, when the flux does not change during the motion, the source of energy supplies only the $i^2 r$ loss. This theorem leads directly to equation (**33**) in Steinmetz's paper.

Emde's investigations have been lately taken up by Mr. E. Jasse (*Elektrotechnik und Maschinenbau*, 1910, p. 833) who has considerably simplified Emde's theory and applied the results to the calculation of performance of a number of commercial forms of electromagnets. Designers of electromagnets will find Jasse's articles very helpful in their work.

Mr. C. R. Underhill deserves considerable credit for a large number of tests on electromagnets. The results were published at different times in the *Electrical World*, and have been lately reprinted in his book entitled "Solenoids, Electromagnets, and Electromagnetic Windings". Professor Silvanus P. Thompson's pioneer work on electromagnets is well known. I wish only to mention his paper on the subject before the St. Louis International Electrical Congress in 1904; the paper will be found in Vol. I of the TRANSACTIONS of the congress.

The relation which connects the mechanical force between the windings of a transformer and its magnetic leakage is treated in Alex. Russell's "Alternating Currents", Vol. II, p. 234, in application to the theory of the constant-current floating-coil transformer. Russell's treatment is more correct than Dr.

Digitized by Google

Steinmetz's because the former considers an infinitesimal displacement of the coils, while Dr. Steinmetz bases his deduction upon a finite displacement until the two coils coincide.

Formula (**56**) for the repulsion between two conductors is as old as Monsieur André Marie Ampère (1775-1836), and in fact was first given by him. It can be derived in the C.G.S. system as follows: The flux density at a distance x from a straight infinite conductor carrying a current i is $B=2\,i/x$ (law of Biot and Savart). According to Laplace's law the mechanical force is $F=B\,i\,l$, where l is the length of the second conductor. Hence, $F=2\,l\,i^2/x$. It is hardly logical to derive this simple result from the variation of self-induction of the loop, because the expression for the inductance itself is originally derived from the law of Biot and Savart. The proof given in Steinmetz's paper will be found in Russell's "Alternating Currents", Vol. I, p. 63.

The preceding references are made not to detract from Dr. Steinmetz's work, but to place the proper credit where it belongs, and to enable those particularly interested in the subject to become oriented in the available literature. In this connection, I wish to make a general plea that papers presented before the Institute be provided with ample literature references, especially giving credit to foreign authors and to papers in foreign publications. The Board of Directors has lately made a highly commendable step in the direction of international courtesy and coöperation, by requiring the numerical values in the Institute papers to be given in the metric system. Requiring proper credit for priority in research and investigations would be in line with this amicable policy, and would greatly enhance the standing of our TRANSACTIONS abroad.

Considerable advantages would accrue to ourselves if the Institute papers were always provided with the most important literature references, namely

1. Repetition would be avoided, papers would be shorter, and the TRANSACTIONS less bulky.

2. Interest would be stimulated to reading or at least referring to many excellent standard works, at present hardly known at all among our engineers.

3. Study of a particular topic would be facilitated beyond the limits of a particular paper.

4. Each paper would be more liable to represent a truly new contribution to the subject, a contribution standing in a definitely stated relation to what is already known, instead of resembling sometimes a chapter from a text-book.

5. The spirit of coöperation would be more emphasized in which many investigators contribute their share to a complete solution of an engineering problem, instead of each working without due regard to the labors of others, duplicating their work, and thus making it extremely difficult for one to become oriented in the present status of knowledge in a particular topic.

Digitized by Google

K. Faye-Hansen: When dealing particularly with the short circuit stresses in alternating current transformers, Dr. Steinmetz has (without specially mentioning it) assumed that at constant current the force exerted by the magnetic leakage flux is the same for the whole distance of movement l until the magnetic centres of the coils coincide. This is however not correct as when the movement has gone so far that the current carrying parts of the two coils touch each other, the magnetic force against any further movement will be decreased. The short circuit stresses figured by Dr. Steinmetz are therefore too low (neglecting the error in decimals). I think that the subject can be handled equally correctly and simply by directly figuring the forces on the current carrying wires due to the magnetic field in the transformer under short circuit conditions. We find that the maximum force is equal to:

$$F=\frac{B}{2}\, n\, i_0\, \sqrt{2}\, d\, \frac{10^{-1}}{981} \text{ grammes} \qquad (1)$$

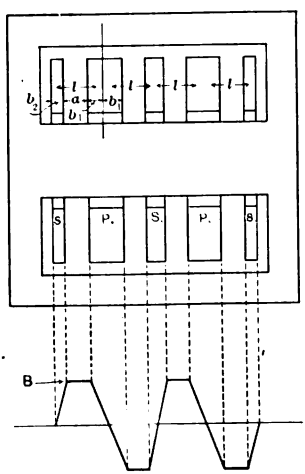


FIG. 1

Where B is the maximum induction in lines per sq. in. between the primary and secondary coils, and $\frac{B}{2}$ is the average of the (max.) induction through the coil: n the number of primary turns; i_0 the effective primary short circuit current in amperes and d the mean length of the turns in cm.

Assuming the form of field as shown in Fig. 1, the volts induced in the primary coils

$$e_0=4.44\, B\left(a+\frac{b_1+b_2}{3}\right) d\, f\, n\, 10^{-8} \qquad (2)$$

Digitized by Google

The value for $B \times d \times n$ obtained by this is substituted in formula (1) gives:

$$F = \frac{i_0 e_0 \sqrt{2} \times 10^8 \times 10^{-1}}{981 \times 2 \times 4.44 \left(a + \frac{b_1 + b_2}{3}\right) f} \quad \frac{i_0 e_0 1620}{f\left(a + \frac{b_1 + b_2}{3}\right)} \text{ grammes} \qquad (3)$$

While if the same dimensions and notations are brought into Dr. Steinmetz's formula No. 54 the result is

$$F = \frac{i_0 e_0 1620}{f\left(a + \frac{b_1 + b_2}{2}\right)} \text{ grammes (the maximum force).}$$

It will thus be seen that the forces figured by Dr. Steinmetz may be as low as two-thirds of those figured under the assumption of the field form given above.

For the actual transformers the difference between the two methods of calculating will however be less than indicated above and usually in the neighborhood of 15 per cent to 25 per cent depending on the ratio between a and (b_1+b_2), *i.e.*, on the voltage, size and design of the transformer.

There is one more point to be remembered—the forces figured above are those which occur when the short circuit current of the transformers has reached its final value. The influence of current rushes however has been neglected. For the first cycles (according to the point of the voltage wave at which the short circuit is switched on)the current may be up to twice its final value and the forces equal to 4 times the value given in the formula.

The method given above for figuring the short circuit stresses in transformers has a further advantage over that given by Dr. Steinmetz—that an estimate of the forces due to the leakage lines bending over the coils can be made using formula (1) if only the lines of force are drawn in (as they would be expected to be) according to the relative size and position of the coils, and similarly an idea can be formed regarding which parts of the coils have to withstand the largest forces.

Dr. Steinmetz' conclusion that the short circuit stresses are inversely proportional to the leakage reactance of the transformer is on the face of it correct, but as the distance between the coils and thickness of them play an important part (as shown in the formula) regarding the forces and also influence the leakage reactance, it will be found that the forces really alter considerably more than in inverse proportion to the leakage reactance at given output, frequency, etc.

J. Murray Weed: For the mechanical forces in a transformer due to the magnetic leakage field, I have obtained results from the fundamental expression

$$S = \frac{B^2}{8\pi} \qquad (1)$$

Digitized by Google

which are identical with those which Dr. Steinmetz has derived. This expression gives, in dynes per sq. cm., both the stress of tension in a direction parallel to the field, and that of compression at right angles to the field. It is the stress at right angles to the leakage field which constitutes the pressure between primary and secondary windings in the transformer, and the approximate value of B which produces this stress may be calculated by the formula

$$B = \frac{\sqrt{2}\, 4\pi\, n\, I}{10\, l\, G} \tag{2}$$

where n is the number of turns in the transformer, I is the effective current, l is the length of the leakage path in centimetres and G is the number of groups of coils. A group of coils here signifies a portion of both primary and secondary windings, with equivalent numbers of turns, adjacent to each other at one surface only. The groups are assumed all equal, so that $n\, I/G$ is the number of primary or secondary amperes turns per group. Substituting the value of B, we have

$$S = \frac{4\pi\, n^2\, I^2}{100\, l^2\, G^2} \tag{3}$$

The area of the surface in which this stress is found is

$$A = (M\, L\, T)\, l \tag{4}$$

where $(M\, L\, T)$ is the mean length of turns. We have therefore, for the maximum force between adjacent primary and secondary coils

$$F_{max} = S\, A \tag{5}$$

$$= \frac{4\pi\, n^2\, I^2\, (M\, L\, T)}{100\, l\, G^2} \text{ dynes} \tag{6}$$

$$= 2.82\ 10^{-7}\, \frac{n^2\, I^2\, (M\, L\, T)}{l\, G^2} \text{ lbs.} \tag{7}$$

These equations give the force for any transformer having n turns, arranged in G equal groups, with a mean length of turn $(M\, L\, T)$ and a length of leakage path l, and with the current I flowing. The force increases with the square of the current, and will have its maximum value when the transformer is short circuited. If the primary terminal voltage is maintained, this

Digitized by Google

current is limited only by the impedance of the transformer, and if the reactance element of the impedance predominates, as it must do in order to give at the same time good efficiency and a proper limitation of the mechanical forces which we are considering, no important error will be introduced by substituting the reactance for the impedance. This reactance may be expressed in terms of the design characteristics of the transformer by means of a formula which, with various empirical modifications, is familiar to designers. Thus,

$$X = \frac{20 f n^2 A'}{10^8 l G^2} \tag{8}$$

The short circuit current is, therefore

$$I_{(sc)} = \frac{E}{X} = \frac{10^8 l G^2 E}{20 f n^2 A'} \tag{9}$$

where A' is the effective combined area of the leakage paths in square inches and l is their length, in inches. If we express A' in terms of its two dimensions, this equation becomes

$$I_{(sc)} = \frac{10^8 l G^2 E}{20 f n^2 (M L T) w} \tag{10}$$

where w is the effective combined width of the leakage paths. It should be noted in equation (**7**) that, since we have one length on the numerator, $(M L T)$, and one in the denominator, l, these lengths may be expressed in inches instead of centimetres without affecting the result.

If we substitute the value of I from equation (**10**) for one of the factors in equation (**7**) we have

$$F_{max} = 1.41 \frac{I_{(sc)} E}{f w} \tag{11}$$

In Dr. Steinmetz' equation (**54**), if we express F in pounds and l in inches, and divide by G to obtain the force acting on a single group, and then multiply by 2 to obtain the maximum force, we have

$$F_{max} = 1.41 \frac{I_{(sc)} E}{f G d} \tag{12}$$

(If Dr. Steinmetz will pardon me for using the letter 'd' in the place of his 'l', I prefer to do this, because of the conventional use of 'l' for the length of the magnetic leakage path.)

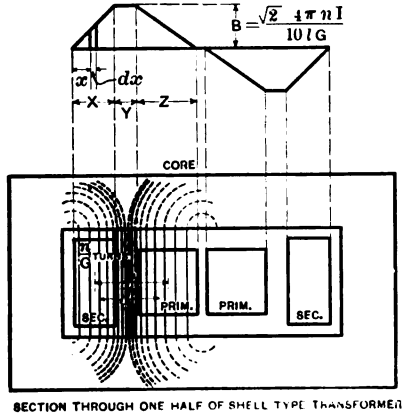
Digitized by Google

If we write

$$w = G\,d \tag{13}$$

and this I think Dr. Steinmetz will grant me, equations (**11**) and (**12**) are the same. This says nothing however, for the accuracy of the assumptions made regarding the effective dimensions of the magnetic leakage field, since any errors in these assumptions eliminate themselves in the calculations. That it is impossible to assign specific dimensions to the leakage field, is illustrated by the easily recognized fact that the length of the leakage path is considerably greater for those portions of the windings which extend beyond the core in the shell type transformer than it is for those portions within the core.

The fact just stated results in a much reduced value of B for that portion of the windings which extend beyond the core,



SECTION THROUGH ONE HALF OF SHELL TYPE TRANSFORMER WINDING IN TWO GROUPS

and consequently in a very much reduced stress. In other words, those portions of the windings which extend beyond the core are not subjected to nearly such great stresses as those portions within the core.

If, now, we return to equation (**7**), and substitute from equation (**10**) for both the factors I, we have

$$F_{max} = 7.05\ 10^6\ \frac{l\,G^2\,E^2}{f^2\,n^2\,w^2\,(M\,L\,T)}\ \text{lbs.} \tag{14}$$

Equation (**14**) will be more useful to the designer than equation (**12**), since it shows the effects of changes in the design characteristics, including the number of primary turns, (if E is the primary voltage), the number of groups into which the windings are separated and the various dimensions.

Digitized by Google

Dr. Steinmetz' method of developing his equation (**54**) seems to involve the conception of a uniform force acting throughout the hypothetical motion of the coils. As a matter of fact, this force would be uniform, and maximum, from the time when motion begins until the adjacent boundaries come together, but would suffer a rapid reduction thereafter, until the centers of the coils coincide, when no force would exist. In order to obtain by equation (**54**) the value of the force active before motion begins (the actual force existing in the transformer), it is necessary to use a value for the length d (Dr. Steinmetz' "l"), which is less than the total distance between coil centers, and such that its product with the initial force will equal the summation of all the products of differential distances and their corresponding forces. This value of d may be determined from the derivation of the reactance formula.

If we multiply equation (**8**) through by I, and express A' in terms of its dimensions, we have

$$\text{React. } E = \frac{20\, f\, n^2\, I\, (M\, L\, T)\, (\overline{G}\, d)}{10^8\, l\, g\, G^2} \qquad (15)$$

This equation is derived as follows. Starting from the left hand end of the core window as illustrated in the figure, and passing through the windings toward the right, the density of the magnetic leakage flux may be plotted as illustrated by the curve at the top of the figure, if we assume a uniform distribution of ampere turns throughout the space occupied by the windings. Assuming that the return paths of the various portions of the leakage field are as represented in the figure, that portion of the flux which exists within the first group of the secondary windings cuts out and in from the left hand side. If B is the maximum flux density between the primary and secondary coils, the density of the elementary portion of flux, within the secondary group, of dimensions $(M\, L\, T)\, d\, x$, is $\frac{B}{X}\, x$.

And if $\frac{n}{G}$ is the number of turns in the group, the number of turns cut by this elementary portion of flux is $\frac{n}{G\, X}\, x$. Adding all the elementary products of flux by turns for that portion of the flux within the secondary winding, we have

$$\int_0^{x} \frac{B\, n}{G\, X^2}\, (M\, L\, T)\, x^2\, d\, x = \frac{B\, n}{G}\, (M\, L\, T)\, \frac{X}{3} \qquad (16)$$

Digitized by Google

Integrating in a similar manner for that portion of the flux within the primary group, and expressing the result in equivalent secondary turns, we have

$$\frac{B\,n}{G}\,(M\,L\,T)\,\frac{Z}{3} \tag{17}$$

For that portion of flux which exists between the primary and secondary coils, the product of flux by turns is

$$\frac{B\,n}{G}\,(M\,L\,T)\,Y \tag{18}$$

the result being expressed in equivalent secondary turns for that portion of the flux which cuts through primary turns. Adding all these results, we have, for the entire group of primary and secondary coils

$$\frac{B\,n}{G}\,(M\,L\,T)\,d \tag{19}$$

where

$$d=\tfrac{1}{3}\,X+Y+\tfrac{1}{3}\,Z \tag{20}$$

The summation of flux turn linkages for the entire transformer is, therefore

$$\frac{B\,n}{G}\,(M\,L\,T)\,G\,d \tag{21}$$

Substituting this value in the fundamental voltage equation

$$E=\frac{\sqrt{2}\,\pi\,f\,N\,\phi}{10^8} \tag{22}$$

we have

$$\text{React. } E=\frac{\sqrt{2}\,\pi\,f\,n\,B\,(M\,L\,T)\,G\,d}{10^8\,G} \tag{23}$$

Substituting again for the value of B from equation (2), and expressing dimensions in inches, we obtain equation (15).

Digitized by Google

The development of formulæ similar to (**15**) have appeared in various text books, and it has been given here only for the purpose of finding the length of d, (Dr. Steinmetz' l), which he has called the distance between the magnetic centers, but which I would call the effective width of the magnetic leakage path for one group of coils. This has been found to be the distance between primary and secondary plus $\frac{1}{3}$ of the distance through primary, plus $\frac{1}{3}$ of the distance through secondary, which is less than the distance from coil center to coil center by $\frac{1}{6}$ of the distance through primary plus $\frac{1}{6}$ of the distance through secondary.

I should like to add, with reference to the formula for reactance, that various empirical modifications are in use, based upon different assumptions as to the dimensions of the leakage path. Also that the linkage of the secondary by leakage flux, as assumed by the return paths shown in the figure, has been questioned. I agree with those who criticize this assumption to the extent that for every linkage of leakage flux with the secondary there must be an equivalent linkage of the main flux in the opposite direction, and wherever these fluxes would occupy the same path, the evident result is the elimination of the secondary linkage. This condition does not exist throughout, however. Thus, for that portion of the winding of a shell type transformer which is outside of the core only the leakage flux exists, the main flux being confined practically to the core. It is a fact, however, that the reactance of the transformer, obtained from the integration of flux turn linkages, will be the same for the given distribution of leakage flux, whether the return paths are as shown in the figure, or all to the right, enclosing the primary.

H. B. Dwight (by letter): The following method of using a well-known equation to obtain some of the formulæ in Dr. Steinmetz' paper, may be interesting as an alternative proof.

The fundamental equation referred to is

$$F = \frac{H\,i}{10} \text{ dynes per cm. of conductor}$$

where H is the average magnetic field in which the conductor lies. This is proved by equating the mechanical work, $F\,d\,l$, to the electrical work, $\frac{i}{10} H\,d\,l$, when the conductor is moved a distance $d\,l$.

1. *Repulsion of Two Parallel Conductors.* The field around a long conductor is found by integrating the effect of the current on a unit pole at distance l from the wire, and is

$$H = \frac{2\,i}{10\,l}$$

Digitized by Google

The other wire lies in this average field, and the force per cm. on it is

$$F = \frac{H\,i}{10} = \frac{i^2}{50\,l} \text{ dynes}$$

$$= \frac{20.4\,i^2\,10^{-6}}{l} \text{ grams.}$$

2. *Short Circuit Stresses in a Shell Type Transformer.* During short circuit, the section of the path for the leakage flux is $m\,l$.

Where m = mean turn

$$l = a + \frac{b}{3} + \frac{c}{3}$$

a = distance between high and low tension coils.

b and c = widths of high and low tension half coils.

The density of the leakage lines is more accurately given by this value of l than by the distance between centers of half coils, which is $a + \frac{b}{2} + \frac{c}{2}$. The effective density of the leakage lines is

$$H = \frac{\phi}{l\,m} = \frac{e\,10^8}{2\,\pi\,T\,f\,l\,m}$$

where T = number of turns.

As the secondary part of a high-low group has a field H on one side, and zero field on the other, the mechanical force is that due to the average field $\frac{H}{2}$, and is

$$F = \frac{H}{2}\ \frac{i_0}{10}\ \frac{T\,m}{g\,K} \text{ grams}$$

where K = number of high-low groups

Therefor

$$F = \frac{e\,i_0\,10^7}{4\,\pi\,f\,g\,l\,K} \text{ grams}$$

Digitized by Google

which is the same result as in the paper.
From this

$$F = \frac{810\, e\, i_0}{f\, l\, K} \text{ grams}$$

which gives approximately 28 long tons for the example considered.

A. C. Zelewsky (by letter): I have read with great care the very interesting and important paper on " Mechanical Forces in Magnetic Fields " and deem it advisable to make a few remarks on the startling results there stated.

Within the last few years I have made, upon the suggestion of Mr. O. T. Bláthy, a considerable series of researches on the forces which act on the coils and conductors of machines during short circuit; and I have always found that with well disposed but not very heavy frames or reinforcements the pernicious effects of these forces could easily be obviated.

The formulas of this paper, on the other hand, give such enormous stresses that a general breakdown could be prevented only by extraordinary care and very expensive devices. In fact, the rush of current on connecting transformers and induction motors in circuit, or on short-circuiting generators would be enough to destroy or seriously damage the windings.

The general expression (**65**) for the mechanical work—or the mean force—and the derived formula (**66**) for absence of saturation, also do not seem to be expressed in the simple forms which they permit and which is a chief advantage of the other results of the paper.

By dealing first with the general system and considering the electromagnet, the transformer, and the parallel conductors only as special cases, a great deal of work may be saved. The mean force—or the mechanical work—are seldom of great interest, because generally the force for a special position or the maximum value of the force have to be determined.

Considering a differential motion of the system, the mechanical work done is

$$F\, d\, l \text{ ergs;} \qquad (1)$$

the increase of stored energy is

$$\frac{d}{d\, l} \left\{ \int_0^i i' \frac{\delta\, \varphi'}{\delta\, i'} d\, i' \right\} d\, l \text{ ergs;} \qquad (2)$$

and the electric energy absorbed by the induced electromotive force is

$$-i \frac{d\, \varphi}{d\, l} d\, l \text{ ergs;} \qquad (3)$$

Digitized by Google

where F is the force exerted, l is the distance in the direction of motion, i and φ are the current and flux (or flux-turns) respectively during the motion, and i' and φ' are general values of current and flux (or flux-turns) respectively as they would increase together from zero to the limits i and φ—all quantities being expressed in c.g.s. units. Applying the law of conservation of energy,

$$F = i\frac{d\varphi}{dl} - \frac{d}{dl}\left\{\int_0^i i'\frac{\partial\varphi'}{\partial i'}\,di'\right\} \text{ dynes,} \qquad (4)$$

which is equivalent to (63) of the paper.*

Another form of this equation can be derived by partial integration:

$$F = i\frac{d\varphi}{dl} - \frac{d}{dl}\left|i'\varphi'\right|_0^i + \frac{d}{dl}\left\{\int_0^i \varphi'\,di'\right\}.$$

$$= i\frac{d\varphi}{dl} - \frac{d}{dl}(i\varphi) + \frac{d}{dl}\left\{\int_0^i \varphi'\,di'\right\},$$

$$= -\varphi\frac{di}{dl} + \frac{d}{dl}\left\{\int_0^i \varphi'\,di'\right\} \text{ dynes.} \qquad (5)$$

Both equations for F are quite general, as nothing has been said about saturation and both i and φ are supposed to change during motion. In practical units they are

$$F = 0.102\left[i\frac{d\varphi}{dl} - \frac{d}{dl}\left\{\int_0^i i'\frac{\partial\varphi'}{\partial i'}\,di'\right\}\right]10^{-6} \text{ kg.;} \qquad (6)$$

and

$$F = 0.102\left[-\varphi\frac{di}{dl} + \frac{d}{dl}\left\{\int_0^i \varphi'\,di'\right\}\right]10^{-6} \text{ kg;} \qquad (7)$$

in which i is now expressed in amperes.

Considering an alternating-current system, the fluxes φ and φ' induce respectively the electromotive forces

$$e' = 2\pi f\varphi' 10^{-8} \text{ volts,} \qquad (8)$$

*Integrating, $W = \int_0^l F\,dl = \bar{F}l = \int_0^{il} i\frac{d\alpha}{dl}\,dl - \left|\int_0^{\alpha i} i'\frac{\partial\phi}{\partial i'}\,di'\right|_0^l$ ergs, which is of exactly the same form as (63) except for differences of notation. [Ed.

Digitized by Google

and

$$e = 2\pi f \varphi \ 10^{-8} \text{ volts.} \tag{9}$$

Substituting these values of the fluxes in terms of the impressed electromotive forces, we have in practical units

$$F = \frac{0.810 \times 2}{f}\left[i \frac{de}{dl} - \frac{d}{dl}\left\{ \int_0^i i' \frac{\delta e'}{\delta i'} di' \right\} \right] \text{kg.,} \tag{10}$$

and

$$F = \frac{0.810 \times 2}{f}\left[-e \frac{di}{dl} + \frac{d}{dl}\left\{ \int_0^i e' di' \right\} \right] \text{kg.} \tag{11}$$

If saturation is absent—and in most cases it can with great approximation be supposed so—the flux is proportional to the exciting current:

$$\varphi' = L i'; \tag{12}$$

so that

$$\int_0^i i' \frac{\delta \varphi'}{\delta i'} di' = \int_0^i \varphi' di'. \tag{13}$$

Adding (**6**) and (**7**) and substituting (**13**),

$$F = 0.051 \left[i \frac{d\varphi}{dl} - \varphi \frac{di}{dl} \right] 10^{-6} \text{ kg.} \tag{14}$$

Similarly from (**10**) and (**11**),

$$F = \frac{0.810}{f}\left[i \frac{de}{dl} - e \frac{di}{dl} \right] \text{kg.} \tag{15}$$

(**14**) may also be written:

$$F = 0.051 \left[2i \frac{d\varphi}{dl} - \frac{d}{dl}(\varphi i) \right] 10^{-6} \text{ kg.;} \tag{16}$$

or

$$F = 0.051 \left[-2\varphi \frac{di}{dl} + \frac{d}{dl}(\varphi i) \right] 10^{-6} \text{ kg.} \tag{17}$$

Digitized by Google

(15) may also be written:

$$F = \frac{0.810}{f}\left[2\,i\,\frac{d\,e}{d\,l} - \frac{d}{d\,l}(e\,i)\right] \text{kg.;} \qquad (18)$$

or

$$F = \frac{0.810}{f}\left[-2\,e\,\frac{d\,i}{d\,l} + \frac{d}{d\,l}(e\,i)\right] \text{kg.} \qquad (19)$$

These equations have also other forms which may be useful in special cases. Introducing reactance,

$$x = \frac{e}{i} \text{ ohms,} \qquad (20)$$

we obtain the three formulas,

$$F = \frac{0.810}{f}\, e\,i\,\frac{d}{d\,l}\left(\log_e \frac{x}{x_0}\right) \text{kg.,} \qquad (21)$$

$$= \frac{0.810}{f}\, i^2\,\frac{d\,x}{d\,l} \text{ kg.,} \qquad (22)$$

and

$$= -\frac{0.810}{f}\, e^2\,\frac{d}{d\,l}\left(\frac{1}{x}\right) \text{kg.} \qquad (23)$$

If x is constant during motion, no force is exerted
If either the current or voltage are constant,

$$F = \pm\frac{0.810}{f}\,\frac{d}{d\,l}(e\,i) \text{ kg.} \qquad (24)$$

where $e\,i$ is the volt-amperes of the system. Except for the numerical coefficient, this is equivalent to equation (54) of the paper. The numerical coefficient is here one-tenth as large. This involves a change in all values for the maximum working pull of electromagnets, for we have
at 60 cycles only 13.5 kg-cm. and
at 25 cycles only 32.4 kg-cm.
for one kilovolt-ampere. Also
86 volt-amperes are required at 60 cycles, and
36 volt-amperes are required at 25 cycles
for a working pull of one inch-pound.

Digitized by Google

In transformers the kilovolt-amperes at short-circuit are easily determined knowing the potential difference at the terminals and the leakage. Supposing the leakage to be proportional to the distance l between magnetic centers of primary and secondary coils, then

$$\frac{d}{dl}(e\,i) = \frac{e\,i}{l}, \tag{25}$$

and

$$F = \frac{0.810}{f}\,\frac{e\,i}{l} \text{ kg.} \tag{26}$$

—again the same result as in the paper except for the numerical coefficient.

Two parallel conductors are repelled with a force which may be determined from the above equations, considering that

$$\frac{d\,x}{d\,l} = \frac{d}{dl}(2\,\pi\,f\,L) = 2\,\pi\,f\,\frac{4\times10^{-9}}{l} \tag{27}$$

and substituting in (**22**),

$$F = 20.4\,\frac{i^2}{l}\,10^{-9} \text{ kg. per cm. length} \tag{28}$$

—exactly the same result as (**57**) of the paper.

Much simpler indeed would it be to start from the formula

$$F = i\,\mathfrak{B} \text{ dynes per cm.,} \tag{29}$$

in which $\mathfrak{B}$ is the flux density at the axis of the conductor. Here

$$\mathfrak{B} = \frac{4\,\pi\,i}{2\,\pi\,l} = \frac{2\,i}{l} \text{ gausses;} \tag{30}$$

so that

$$F = \frac{2\,i^2}{l} \text{ dynes per cm.,} \tag{31}$$

or in practical units,

$$F = 20.4\,\frac{i^2}{l}\,10^{-9} \text{ kg. per cm.} \tag{32}$$

as already given.

Digitized by Google

E. Jasse (by letter): I would like to call attention to an article covering the same subject which I published in "*Elektrotechnik und Maschinenbau*", *Zeitschrift des Elektrotechnischen Vereines in Wien, Heft* 40, 41 *u.* 42, 1910. In this article the equations 5, 6, 15*a*, 7 and 15*b* are equivalent to equations 1, 11, 16, 33 and 37 of Dr. Steinmetz's paper.

C. P. Steinmetz: Professor V. Karapetoff's historical review of the theories used in my paper is very interesting and important if complete. I never give literary references, however, for the reason which I stated in the preface of my first book:

"I have omitted altogether literary references, for the reasons that incomplete references would be worse than none, while complete references would entail the expenditure of much more time that is at my disposal, without offering sufficient compensation". (A. C. Phenomena, 1897).

As it is obvious that no paper has ever been written, which does not use the work of preceding investigators, the absence of literary references does not claim originality for every detail. When crediting priority of a conception however, the serious danger is the possibility of unfairness, by overlooking the first publication on the subject, and thereby giving credit where it does not belong. This can be guarded against, to some extent, only by such an extensive search of the literature, as is usually out of the question. Nevertheless, it is undoubtedly desirable, at least historically, to give references. This however is work, which the college professor can do very much better than the practicing engineer, as he has the time and the facilities, and I therefore express the hope, that our colleges will undertake this work of keeping the historical records of the electrical engineering science.

That the mechanical forces, with which my paper deals, are not a mere theoretical conception, but are very real, no one can gainsay who has had anything to do with transformers which have passed through a short circuit. I mean transformers of large size, built with very close regulation, from mistaken engineering notions, usually on the express requirement of customers which have forced the manufacturers against their better knowledge to design for a reactance of two per cent or even less. If such a 5,000 kw. transformer of close regulation passes through a short circuit on a system which really can maintain the voltage at the primary—a system with momentary short circuit power of millions of kilovoltamperes, as there are now quite a number in this country—the closest approach to the appearance of such a transformer is the way that I think two express trains must look after a head-on collision at high speed.

It is true that these destructive agencies have been at work more in the last years than before, but the reason is obvious—it is due to the systems on which the transformers are installed—we did not have these large power systems a few years ago, but they are increasing now more and more rapidly—which can main-

Digitized by Google

tain constant primary voltage with a secondary short circuit on a big transformer. In a small transformer the forces are relatively less, but they are enormous in big transformers, and what really was saving the transformer, and now still saves by far the largest majority of the transformers, is the inability of the generating system to maintain the primary voltage under secondary short circuit, and the forces go down with the square of the current, that is, with the square of the impressed voltage. If for instance, as stated by one of the speakers, amongst many transformers tested, with five times full load current, one showed distortion—I think that is rather a condemnation of the mechanical construction—as at five times full load current the mechanical strains are only one hundredth of what they are at short circuit, with 50 times full load current, and a test with five times full load current thus is meaningless in indicating the ability of standing the short circuit stresses.

All engineering theory consists of three parts: first, to find out that a thing exists; second, to get the general theory, which is really the theory of the phenomenon as it would exist under ideal conditions, conditions which never exactly but only approximately exist in practice, for instance, parallel circular conductors carrying uniform current density, and the third part is the adoption of those general theories to the specific conditions under investigation, the calculation of the exact distance of the equivalent magnetic centers of the coils of the transformer which I referred to in the paper—the calculation of the equivalent location of conductor centers which represent the forces between parallel rectangular bus-bars—all these things are of importance in the investigation and consideration of the secondary phenomena which modify the effect of the primary or general phenomenon, which constitutes the subject matter of the paper, and I think it is very gratifying to see that the discussion has already extended to these secondary questions by giving us a very explicit study of the secondary actions which have to be considered in applying the general equation to the specific cases of rectangular conductors, of transformer coils, etc.

Digitized by Google

DISCUSSION ON "EFFECT OF TEMPERATURE ON THE HYSTERESIS LOSS ON SHEET STEEL", "COMMERCIAL TESTING OF SHEET IRON FOR HYSTERESIS", NEW YORK, APRIL 14, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

C. H. Sharp: It may not be amiss to consider very briefly some of the improvements in method and apparatus for magnetic testing and also some of the difficulties which are met with in this class of work.

Testing by the ballistic galvanometer method has been greatly simplified by the use of a long period D'Arsonval galvanometer as ballistic instrument in place of the old undamped moving needle galvanometer which made such a record for itself as a troublesome and time-wasting instrument. The D'Arsonval galvanometer is given any required degree of damping so that it may be used without a loss of time in bringing it to rest. It is calibrated by reference to a standard of mutual induction and its constant is expressed no longer as a ballistic constant, but rather in terms of line of force cut per centimeter throw. The long period is required not so much to enable the throws to be read with accuracy as to obviate the effects of magnetic viscosity in the specimen.

The errors involved in the use of yokes in testing straight specimens have been taken account of and yokes with compensating windings which carry sufficient current to overcome the magnetic reluctance of the yokes, joints, etc., have been devised and put into practical use.

The Picou permeameter, an instrument designed on this principle, has been found in our work to have a very limited range of usefulness and not to be a successful practical instrument. The investigations of the Bureau of Standards along these lines have been most thorough and painstaking and have resulted in the development at the Bureau of Standards of practical forms of compensated yokes wherewith really accurate permeability and hysteresis tests can be made with a reasonable expenditure of time.

Among instruments intended for giving a relatively quick determination of permeability curves and hysteresis loops, by substituting a more convenient device in place of the ballistic galvanometer, the Koepsel instrument has probably a predominate place. The compensation of the yoke reluctance in this instrument, however, is very imperfect and the results obtained for it require so much correction to take account of the unknown reluctance of the yoke, and of the joints, that it can hardly be considered as giving very accurate results in any work except in the comparison of samples of similar material.

Practically, not only the hysteresis loss but also the eddy current loss should be known. This fact leads directly to the wattmeter method of testing samples. If the iron is tested at the same induction with two different frequencies of the

Digitized by Google

alternating current or if it is tested with the same frequency but at two different values of the induction, the eddy current and hysteresis losses can be separated from each other. There is no practical difficulty in measuring the losses in even quite a small sample of iron if the proper instruments are available. The wattmeter used must be one which is accurate on low power factors. If the sample is quite a small one, some special sensitive wattmeter is required such as for instance, the suspended type, using a mirror and spot of light for reading. It is advisable to use a separate winding for the potential measurements as Professor MacLaren has done. Sometimes a third winding is put on which is connected to an electrostatic voltmeter. Under these conditions the electrostatic voltmeter indicates the total e.m.f. set up in the winding, and consequently the maximum induction; that is no correction is necessary for fall of potential in the windings, due to the voltmeter current. The temperature of the windings and of the sample should be accurately controlled and the temperature at which the losses are measured should be stated. This is very seldom done, but in as much as the eddy current loss must have the same temperature coefficient as the resistance temperature coefficient of the iron; namely about 0.5 per cent per degree, the necessity for stating the temperature is obvious. Inasmuch as the sample may tend to rise considerably in temperature during a test, it has been found in our work advisable, at any rate when working with small samples, to immerse the entire arrangement in an oil bath. Furthermore, if the temperature of the oil bath is kept at some definite value, as for instance 50 deg. cent. the losses are measured at a temperature comparable with the temperature which the iron will actually have in use. It would be advisable therefore that a standard temperature at which these tests are to be made should be agreed upon.

The test should be made with a sine wave form. This is required because the losses vary with the wave form. It is not sufficient simply to assume from the fact that the wave form of the generator is practically sinsuoidal, that the form factor, which enters directly into the computation of the maximum induction produced in the iron, is exactly 1.11. The actual form factor of the wave of e.m.f. set up in the iron should be investigated and its actual value determined. Any error in the determination of the form factor affects the value computed for the maximum induction by the same percentage, and consequently affects the value for the losses at a given induction by a considerably larger percentage. The form factor may be determined either from an actual plot of the wave, or by rectifying the wave by means of a commutator attached to the shaft of a synchronous motor, and comparing the value of the rectified e.m.f. as indicated by a permanent magnet voltmeter with the value of the alternating e.m.f. as measured by a dynamometer type of voltmeter containing no iron. In this arrangement it is not always easy to be sure

Digitized by Google

of perfect contact between the commutator and the brush, so that a good deal of care needs to be used, to avoid error from this cause.

The pieces from which the magnetic circuit is built up need to be carefully insulated from each other. The exact method of building a magnetic circuit does not seem to be a matter of great importance. In the Bureaus of Standards apparatus the joints at the corners of the magnetic square are more perfect than in the Epstein apparatus so commonly used in Germany. The result of this is that the wattmeter is used at a better power factor. In the Möllinger apparatus the samples are continuous, ring-shaped stampings and the windings are quickly put on by a special arrangement. This gives a more perfect magnetic circuit than either of the other forms, but requires a less economical form of stamping and gives practically the same results as the Epstein apparatus. Wild, in a recent paper before the Institution of Electrical Engineers, reported finding several per cent higher loss in the Bureau of Standards' style of magnetic square than in the Epstein style. He attributes this to the increased hysteresis in the corner pieces due to bending, and considers the results of the Epstein apparatus to represent more nearly the true values.

The question of the sample seems to be the most difficult one in connection with the wattmeter method of testing. In the Epstein apparatus 10 kilograms of iron are used. The quantity is so considerable and the individual pieces are of such size that the resultant sample can scarcely fail with proper selection, to be representative of the iron. Where smaller samples are used, the doubt increases as to the representative quality of the sample, and this seems to be the chief difficulty in the use of small samples for the wattmeter test.

Mr. Robinson's method presents the wattmeter test reduced to the greatest possible simplicity. The only question about it seems to be that of the size of the sample and in as much as Mr. Robinson has found it to give satisfactory results in the immense amount of work which he has done with it, and the results of which have been of the very greatest commercial importance, it is hardly open to doubt that as a workshop method his is a most excellent one.

Edwin F. Northrup: I have been interested in Professor MacLaren's paper on methods of hysteresis testing because of the importance of the subject, and also, for what the paper tells and suggests.

While I do not feel as competent to discuss methods of iron measurement as I would methods of electrical measurement, nevertheless I have some thoughts regarding the subject of the paper which may be worth expressing.

In addition to the losses in a transmission system which result from depreciation of the equipment there are two sources of loss which have received a searching study, namely, the

Digitized by Google

copper losses on the line and the iron losses in the generators and transformers. The control of the copper losses has become so good that it is not unreasonable to specify conductivities for the copper, or aluminum conductors, used to within a fraction of a per cent, and conductivity measurements can be made by a single observer with great rapidity to within a quarter of one per cent. Yet, without data at hand to confirm the suggestion, I should suppose that it is costing thousands of dollars to overcome unnecessary hysteresis losses, to hundreds of dollars spent in overcoming unnecessary copper losses. Severe specifications respecting the quality of conductor materials, in the present state of engineering development, can be made with much better justification than they can respecting the qualities of transformer irons and steels. This is in part due to the fact that conductivity measurements are so much more easily and precisely made than iron measurements. Any contribution, therefore, to our knowledge of practical methods for making iron measurements is welcome.

Iron measurements have directly in view a commercial end and in devising methods for making measurements one should work from the commercial view point. Laboratory precision, as applied to many electrical measurements, is of relatively small importance in making iron measurements as compared with simplicity, rapidity and the use of few observers.

Professor MacLaren presents us with two methods of testing iron, and with the first of these methods he obtains results which are very interesting. His first method, the wattmeter method is not new but his second method, the direct measurement of hysteresis, is, as far as I know, described in print for the first time. I have had the opportunity of examining the construction of his samples, the apparatus used in his tests, and myself have made a trial of his second method. I am convinced that his work was done with painstaking care and that all his statements are conservative. His construction of a furnace for regulating the temperature of the samples, I think is particularly well adapted to what it has to do.

The curves, giving the relation, between watts lost per kilogram of steel, and degrees centigrade, are interesting in the extreme. It would appear from these curves that a reduction in the hysteresis loss to one fourth its original value, by an elevation of temperature of some 500 deg., is a physical fact and one of much significance. It looks as if the molecules turn about under the directive force of the magnetic field with less friction as they become further separated by elevation of temperature. One should also expect considerable diminution in the eddy-current losses, with elevation of temperature, from the increase in the specific resistance of the iron. Referring to tables I, II, III, of the article we find this not to be true throughout the entire ranges of temperature used. In table I, for any given induction, say 10,000, we have the eddy-current loss, starting at 24 deg.

Digitized by Google

equal to 0.312 and falling at 390 deg. to 0.166, but then rising again at 535 deg. to 0.246 and continuing to rise at 708 deg. to 0.92. Sample No. 1 was thought to be defective in insulation, but there is no regular decrease beyond 597 deg. even in sample No. II, table II. If both the hysteresis loss and the eddy-current loss in transformers decidedly decreases with elevation of temperature, and if the decrease in loss should prove to exceed the increase in copper losses, and if the elevated temperature does not gradually diminish with time the permeability of the steel, it might actually result that transformers would show a total higher efficiency when run hot than when run cold. It is doubtful if experiment would justify this conclusion, but I suggest it as a research for some one, to make a prolonged test of the relative efficiencies, of properly insulated transformers operated at, say 40 deg. temperature and 200 deg. temperature. It is not improbable that the insulation problem could be cared for with asbestos covered wire and some of the new insulating compounds.

The data at the bottom of page 548, in which Professor MacLaren finds that the curves, showing change in induction as the iron passes through the magnetic point, practically overlap, both for an increasing temperature and for a decreasing temperature, have, to my mind, an important physical significance. On many samples of steel tested by me, to determine their heating and cooling curves, I found that in all cases the recalescent point lay some 26 deg. or more below the decalescent point. In one low carbon steel the decalescent point was at 724.4 deg. C. and the recalescent point at 676.4 deg. C., In this case the two points were separated by 48 deg. In the case of a high carbon steel the decalescent point was at 728.4 deg. C. and the recalescent point at 702.4 deg. or a difference of 26 deg. Now, as iron or steel is supposed to lose its magnetism, when it passes through the decalescent point and to regain its magnetism when it passes through the recalescent point, it is quite remarkable that Professor MacLaren should find the induction on heating the sample to be 6010 at 727 deg., and to find the induction on cooling the sample to be 6015 at 726 deg., which is practically the same thing. Perhaps a sample of steel when under the influence of an alternating magnetomotive force will have its recalescent point and decalescent point located at the same temperature. This is worth a trial for the physicists.

Professor MacLaren's second method of the direct measurement of hysteresis has the very great advantages of being applicable to an extremely wide range of induction, of giving the data, for plotting the hysteresis loop, in about ten minutes, and of being, to a certain extent, self checking (as the sum of the deflections for change of induction in one direction must equal the sum of the deflections for an equal change of induction in the opposite direction). It has the disadvantage from a commercial standpoint of requiring from three to four observers. Then,

Digitized by Google

also, the reduction of the data and the plotting of the curves require considerable time. I believe the method could be made very much more rapid, as well as more accurate, by making it partly automatic.

It would be a simple matter to construct a recorder, whereby the galvanometer deflection would be recorded as a sinuous line upon a cylinder revolving uniformly with the time. The same recorder, or another one, could be made to record synchronously on another revolving cylinder, the change in the magnetizing force. From the two curves so drawn automatically, to a proper scale, the data could be taken for drawing the hysteresis loops. The delicacy of the galvanometer required would be no impediment to such automatic recording, as much more difficult problems, in the automatic recording of temperatures registered with very sensitive galvanometers, have been already solved commercially by myself and others.

It seems to me that progress in iron measurements should follow along the line of seeking greater rapidity in taking the data in methods of rapidly reducing the results, and in making automatic, processes now performed manually. To accomplish these results I can say with a certainty only requires capital and enterprise.

J. A. Capp: Mr. Robinson has described two sets of apparatus for measuring the hysteresis loss in sheet iron samples. A brief statement of about ten years' experience with the apparatus, using the bundle of 10 in. x $\frac{1}{2}$ in. strips, in the commercial testing of sheet iron may be of interest.

The first and most obvious use of the test method was in the inspection of raw material and its testing to determine whether or not it conformed with the standard established in the specifications. Consideration of the many points which have bearing upon the preparation of purchasing specifications soon indicated that such specifications must define the required chemical composition of the steel and its manipulation in the rolling mill. At the time when this work was begun, the rolling mills were generally not equipped to make tests to determine the magnetic quality of their product but they did understand the chemistry of the steel and, of course, had control over mill processes. Experience shows that relatively hard sheets can be punched with greater ease to a given degree of accuracy than softer or thoroughly annealed sheets. It had long been recognized that heat treatment has fully as great an influence upon the quality of the sheets as composition. The use of the relatively hard sheets immediately then requires that the final heat treatment be done by the purchaser and it is obvious that the manufacturer cannot be held accountable for the results of a treatment applied by the purchaser and over which the manufacturer can have no control.

The next, and what has since turned out to be the most important use of this convenient means of commercial testing

Digitized by Google

was the determining of the best treatment to apply to sheets to put them in a state having the maximum permeability with minimum hysteresis. This work was undertaken by selecting typical lots of steel from the standard commercial output of several manufacturers and from which lots of steel a very large number of 10 in. x ½ in. strips were cut. These strips well mixed, so as to be broadly representative of the lots from which they were taken, were made up into the one pound samples required in the hysteresis testing outfit. The hysteresis loss and permeability were determined for each of the samples and different samples were then carried through a long series of heat treatments, designed to indicate the influence of the rate of heating, the rate of cooling, the time the maximum temperature was maintained and of all the other variables which necessarily would enter into heat treatment of this character. In this series, thousands of samples were tested and the results when completed, indicated the desirable heat treatment of steels of the compositions and characters included in the lots selected.

This work provided the basis for the preparation of standard specifications which could be used by the purchasing department in their contracts for the sheet steel purchased. These specifications as already indicated, state the required composition of the steel and then define its manipulation by the producer, hence inspection testing substantially resolves itself into a matter of chemistry. But the question of proper mill manipulation still can be determined with reasonable dependence by the application of the prescribed heat treatment to the steel, when if the manipulation has been that specified, the hysteresis loss and permeability should equal at least a certain standard.

The necessity for heat treating the steel purchased at once requires that there be means of determining whether the prescription for heat treatment is actually being carried out in practice. The direct measurement of the temperatures used in the heat treatment is possible at least in certain parts of the furnace by pyrometers. It is obvious that a pyrometer can only measure the temperature of the particular point in the furnace at which it is placed and furthermore it is well understood that the indication of the pyrometer is more or less an average of the conditions surrounding its point of location. These considerations led to the use of hysteresis testing outfit as a check upon furnace work and an elaborate scheme was worked out for the exploration or the annealing furnaces by pyrometers and hysteresis test samples. Large numbers of the test samples were distributed throughout the annealing pots, as many as five or six hundred samples being used in one annealing heat. These samples had been taken from lots of material the history of which was thoroughly known and upon which the influence of varying heat treatment had been extensively studied. Hence the results obtained in the hysteresis outfit upon the test samples which had been distributed throughout the annealing pots

Digitized by Google

enabled us, with reasonable accuracy, to determine the distribution of temperature in the furnace and pointed to the way to correct inequalities in this distribution, and to establish a routine for the furnace manipulation. This routine, when followed, is expected to yield uniform results, but hysteresis test samples are regularly used as a check upon furnace work, and the heat treatment operations are controlled through the joint use of pyrometers and the hysteresis testing outfit. Samples are placed in the pots at what experience has shown are apt to be the hottest and the coldest parts, and when the test samples show results below normal, the punchings in the particular part of the pot represented by these poor samples may be sent back for reannealing. Obviously the samples which are used in this way must be taken from stock which previous testing has shown will respond properly to the prescribed heat treatment, though it is but fair to say that almost no selection is required for this purpose, since the specifications provide a grade of steel which can be turned out by the producers with a highly satisfactory degree of regularity. Results are checked by tests upon samples taken from the actual punchings themselves and these confirm closely the results from the regular heat samples.

Still another commercial use may be made of a method of testing such as has been described. There are times when by reason of unusual service conditions, or because of unusually stringent specifications on the part of a customer, apparatus must be turned out which must be classed as special, because the core losses are required to be lower than in standard apparatus of similar design. In such circumstances, it is not always possible for the designing engineer to take care of the special necessities of the case in any other way than by the use of special material. Standard specifications provide material which, after proper heat treatment, may be expected not to exceed a certain maximum hysteresis loss. The average, however, is, of course, considerably below this maximum and there may be found exceptional lots which will run at a very low minimum. By having available a means of testing which requires but small quantities of material and the results from which can be quickly obtained, it is possible to go through stocks which could be used for the production of such special apparatus and select those particular lots which will run at or below the average. Advantage has been taken of this possibility in some of the rare cases where the designing engineers have been forced to require the use of specially selected material.

Mr. Robinson has discussed at some length the question of the general accuracy of the results obtained with the outfit using the 10 in. x $\frac{1}{2}$ in. specimens. Experience has shown that when a line of machines has been designed using material which has been tested extensively by this method and which machines after completion have been put through the usual tests, the designing engineer is provided with data upon which

Digitized by Google

he may determine within close limits the core loss of machines of new design. We were at one time able to determine from tests made on the 10 in. x ½ in. samples that the manufacturing processes of one of the sheet steel mills had gone astray. Had we not been able, at least with a very close approximation to accuracy, to make tests upon a large number of samples so as to determine that it was actually temporarily characteristic of the output of that mill that we could not get the expected results, we would have been forced to work in the dark and probably would not have been able to prevent the use of a good deal of poor material in commercial apparatus. We were able so to impress the mill representatives with the results shown them that they made an investigation only to find rather to their astonishment that a supposed improvement had been made in the process by a man in the mill who had not thought it necessary to bring the change to the notice of his superiors.

When the apparatus was first set up for use, there was some doubt whether readings could constantly be duplicated on the same samples. Therefore, a number of samples representing a wide range of results was tested and laid aside under lock and key. These were taken out at irregular intervals and tested for a period of some two or three years. The greatest variation found was not over one per cent which, of course, is considerably less than the normal variations to be expected in a large number of tests representing one particular lot of material.

The foregoing has shown that a very considerable commercial use is being made of the testing outfit described. This extensive use, however, is made possible only by reason of the speed with which results may be obtained and by the comparatively small weight of material which is required in the test. Mention has been made of the use of the method as a check upon the material received to indicate conformity with specifications, and as a check upon the heat treatment applied in the annealing furnaces, which check is accomplished not only by the testing of the samples which are prepared and placed at predetermined points in the annealing pots but also by tests upon samples punched from the material actually annealed. Tests of the samples are made not only before and after treatment, but also upon a considerable proportion of them after subsequent exposure to moderately elevated temperatures to determine the amount, if any, of increase in hysteresis due to what is commonly called aging. This together with experimental work, requires the testing of an average of about 600 samples per week. The samples are delivered to the laboratory in the form of loose strips 10 in. x ½ in. These must be assembled into the one pound bundles, the top strip of which is stamped with an identifying number. The bundles are weighed and the necessary data entered in a record book. The samples are then turned over to the furnace men by whom a record is delivered to the laboratory showing the location of the several samples in the various pots. This data is

Digitized by Google

added in the record book, together with the results of tests before and after heat treatment and aging. Results are then entered on a blank report form which is sent to the parties who must know the detailed results.

Mr. Robinson has briefly referred to the necessity for economy in the use of material where a large number of tests is to be made. This is obvious when it is considered that the test samples are not of suitable size or shape for productive use, and hence may become an item of expense worthy of consideration. Furthermore, room in annealing pots may not be taken up unduly by test samples without reduction of productive capacity, hence the test samples must be small in volume and of such shape that they may readily be placed in the annealing pots without interference with the regular production material. Special shearing devices have been provided for cutting the 10 in. x ½ in. strips so that the waste of iron is at a minimum. We have stated that there are an average of 600 tests per week made and reported. Some of these tests are repeated on the same sample so that there are actually required about 500 samples or an equivalent number of pounds. Each sample consists of an average of 52 strips of fourteen mil iron. Hence, there are about 26,000 strips of iron handled per week in making up the samples. Obviously, if the sample were larger than that now used, the weight would be increased proportionately as well as the cost of material consumed, and labor of handling.

From all this, there may be formed an idea of the amount of labor involved in the testing and clerical work. Perhaps the best indication of the speed with which the work may be done is the statement that all of this work is carried on by two men who have time left to do the laboratory annealing experiments which are constantly in progress.

L. W. Chubb: The magnetic testing of sheet steel had been a very active subject for the last few years, especially during the development of the silicon steels. I have no formal notes on these papers to-night, but some points have come to my attention that I would like to ask some questions about. Is it not true that the use of windings of iron wire, referred to in Professor MacLaren's paper, is a source of error. If, when the temperature gets high, the permeability is very much reduced, excessive exciting current in the iron wire would cause distortions of the induced voltage and the flux in the sample. Such distortions would apparently lower the hysteresis loss and be caused by decreased permeability, even though there would be no decrease in the area of the true loop of the steel. It would seem as though the combined resistance and inductance of the iron winding would cause drops and distortions, resulting in hysteresis errors of several per cent. No data has been given for the high induction points at high temperatures, and I therefore assume that reduction of permeability was a limiting feature. I would like to ask Professor MacLaren if any results

Digitized by Google

were taken showing the relation between permeability and temperature.

Mr. Robinson's paper treats of testing methods that need to be carried on very extensively in a large commercial factory. In our work we use a single method with a sample which is between the one pound sample and the standard Epstein sample described in the paper.

In certain work it is the custom to use steel without annealing after punching, and the sample consisting of small strips 10 in. x ½ in. does not give a representative result for the steel. The variations in a commercial sheet of steel are as great within the sheet as between separate sheets, and therefore the test with the small sample is not satisfactory, not only because of the damage due to cutting small strips, but also because such a sample does not sufficiently cover the area of a commercial sheet. To get a representative one-pound sample from a sheet or lot of steel, it is necessary to resort to some complicated scheme of cutting, which is laborious and wasteful of material.

Our Epstein apparatus uses samples of fifteen pounds of strips 15½ in. long by 1 3/16 in. wide. The results obtained with the 15-pound sample check results obtained with the standard Epstein samples. Several details in the method are different. The first I will mention is the use of a secondary winding. In our apparatus we take the potential for the wattmeter coil and for the voltmeter directly over the exciting winding. This includes in the wattmeter reading the $I^2 R$ loss in the windings. The voltage drop in the winding also tends to reduce the measured core loss.

At first sight it would seem inadvisable to introduce such errors in the testing method, but we have found by very careful ballistic exploration of the Epstein sample that the error due to the leakage at the corners is greater than the resultant error caused by the $I^2 R$ loss and the $I R$ drop in the winding. Since resultant copper error and the leakage error are in the opposite direction, and are both functions of the permeability of the steel, they will always cancel the effect of each other to a certain extent, and when the coils are properly proportioned the method will give better results than when a secondary winding is used.

Dr. Sharp brought up the point that the results in Professor MacLaren's paper given by the ballistic method and by the wattmeter method do not agree exactly. Mr. Robinson shows in his paper a rather close agreement between the two. Many researches on the comparison of the wattmeter and the ballistic methods have generally shown the ballistic results to be lower than the hysteresis part of the wattmeter results, which seems to be correct.

When flux grows in a lamination of finite thickness the eddy currents will cause a skin flux, and the induction will not grow with uniform rate throughout the lamination. This will result in a variable maximum induction and increased hysteresis loss.

Digitized by Google

Work done by Dr. Lloyd shows that only when the laminating of the steel is very fine will there be a close agreement between the hysteresis loop taken ballistically and the hysteresis per cycle, taken by the wattmeter test. I believe that the reason Mr. Robinson's results check as close as they do is because he takes his voltage from a secondary winding, and the leakage error causes a reduction in the measured loss.

Mr. Robinson states in the paper that the flux variations due to leakage amount to not more than eight per cent. I assume that he means variation at an induction of 10,000 lines. Exploration of the sample under direct current excitation has shown that the leakage at the corners is very much greater and the resultant error to be more than one per cent. The design of Mr. Robinson's apparatus, the Epstein apparatus, is novel, and I believe it is a very fine scheme. We use corner blocks and clamps similar to those shown on the Epstein set in Fig. 4.

Repeated tests have shown variations between the results obtained by different operators, while the same operator can test a sample repeatedly and get the same result. The variations were found to be caused by differences in clamping the corners and pounding the corner blocks. I believe the clamping scheme shown in Fig. 5 is a great improvement over the usual Epstein corner blocks, and will do a great deal toward eliminating the personal equation in testing with a given set of apparatus. The other advantages mentioned in the paper are also of great importance, and make the adoption of the new clamping method seem advisable for standard Epstein apparatus.

R. B. Treat: A comparison of the two pieces of apparatus indicates that testing by means of the one pound sample is economical only for sheet makers or users who require many tests per week. The 10 kilogram apparatus is the more economical for a few tests per week, or infrequent tests, because of the use of commercial instruments which are available for other tests and are returnable to the makers for repairs and good results can be gotten by the average operator. The one pound apparatus requires the maintenance in usable condition of infrequently used special instruments, a thing very annoying and expensive. The high cost of material in the 10 kilogram samples is a disadvantage, but is to be preferred to the special instruments of the one pound apparatus.

Mr. Robinson takes it for granted that we are familiar with many of the minor details involved in the tests. It may be well to mention the importance of a few of them. Users of steel find it necessary to check the quality of incoming material with the supplier's guarantee and with specification. The samples should be sheared but unannealed, unless there is an agreement with the supplier that he will accept annealed tests. Ordinarily the purchaser of sheet steel must be able to test the suppiled material without subjecting it to any questionable process, such as punching or annealing. Some so-called annealing is ruinous to the material.

Digitized by Google

Users of steel require also to know the properties of the material when incorporated in the finished apparatus. For this information the samples may be either sheared or punched, but should receive an annealing identical to the usual manufacturing process.

Mr. Robinson chooses a width of sample such that the effect of shearing is small, but while small in a sheared sample it may be very large in a punched sample, for these reasons: Shearing must be a clean cut, or there will be no cut at all, while a punch may cut cleanly, or it may mechanically disturb the metal for a considerable distance from the edge of the sample.

Samples can be japanned or shellac coated at a very small cost, so it is advisable to do this and thus minimize the effect of fins on the edges. Japanning increases the weight of the sample about one-half of one per cent, depending upon the thickness of the coat. Annealing may change the specific gravity of the sample, under some conditions it increases the weight about two-tenths per cent both dependent upon the exposure of the sample to the annealing heat.

It would be well to settle upon a method of determining the cross-section of the sample, and consequently the value of "B". This should be calculated from the weight and the longest dimension, for the percentage of error in taking this dimension is least of all.

It is very unreliable to micrometer individual sheets or even a squeezed pack.

Area determined by weight, and that by linear dimensions, may differ by ten per cent. The weight per cubic inch of silicon steel is about 0.271 lb. and common steel is about 0.275 lb., one and one-half per cent difference.

The butt joint with its paper insulation, has the advantage over the lap joint in that the flux is less likely to pass through the sheets at the joint, which might set up local eddy currents. The butt joint however causes leakage which has the effect of apparent higher core loss. This is easily demonstrated by successive tests with varying insulation in the joints and has been discussed by the Washington Bureau of Standards.

The Magnetic Committee of The American Society for Testing Materials has given the subject of sheet steel tests considerable study and we may hope it will soon settle upon a standard method for the use of both the maker and user of electrical sheets.

W. J. Wooldridge: Several speakers in referring to Prof. MacLaren's paper have spoken of the probable errors due to the use of iron wire for winding. The paper as a whole seems to fill in a gap in our knowledge in regard to steel.

It would perhaps be interesting to bring to your attention again the fact brought out by Ewing in his book on Magnetic Induction of Iron and other Metals, in which he points out that the permeability at very low inductions increases with increasing

Digitized by Google

temperature up to 775° C. and then decreases very suddenly between 775 and 786 deg. cent. At medium intensities that is less marked, while at high intensities the permeability falls off continuously, it does not increase as it does at low intensity—but falls off continuously, and falls off more rapidly at the end. In this connection it has been a question in my mind, and the minds of several people I have talked with from time to time, as to whether there was really some relation between hysteresis loss of high density and permeability. We know that at low densities there is no such relation, because with an alloyed steel, the permeability at very low densities is very much better than in standard iron, but these permeabilities cross somewhere about 12,000 *B*, if I remember rightly, and it has been a question whether on densities over that there is or is not some relation between the hysteresis and the permeability. The results of this test would apparently show that there is no such relation, and therefore this paper fills a gap on a point concerning which we did not have definite knowledge before.

As near as I can make out in table III, the logarithmic relation between the hysteresis loss at various densities does not follow the 1.6 law. One of the speakers has mentioned that the eddy current loss does not vary as everybody supposed it would, *viz.*, that it should be stated as varying inversely as the specific resistance. The eddy loss in ordinary iron, at normal densities and frequencies is, roughly, 30 to 35 per cent. Silicon steel has between four and five times the specific resistance of ordinary iron, but the eddy loss is reduced only to 18 or 20 per cent, which does not follow at all the supposed law in regard to specific resistance.

W. R. Whitney: In the Research Laboratory we have found, after considerable experimental work, that it is desirable to employ as small samples as practicable for test. The reasons are almost obvious. Small samples of new material are usually much easier to obtain than large ones. Experimental work on these samples, such as heat treatments, compression and bending experiments, etc., can be more easily performed than on large samples. A relatively large number of separate samples can be taken from a small sheet of iron, and by taking the average of measurements on many small samples, results are sometimes obtained which would be concealed by the measurement of the hysteresis of the same quantity of iron in a single sample. For this reason we have often used a Ewing tester, where separate measurements were made on each ounce of iron, and have followed up the leads opened by such tests, by means of the standard factory one pound samples. In experimental work it is very important that all unnecessary barriers be removed from the way of quick and easy production of samples. It is preferable if the iron can be cut, annealed and tested in the same room and by one man.

Samples must also be capable of quick and simple measure-

Digitized by Google

ment, and finally, large numbers of the identical tested samples should be kept on hand for later reference.

This is all very easy with one ounce samples, but the Ewing tester, in our hands, is little better than a qualitative instrument, so that we have always referred to one pound samples for accurate conclusions. Such samples are also still small enough so that care and storage of them is not a serious matter. When the tests are made on twenty-two pound samples, it becomes evident that even the cost of the samples themselves is a factor where much testing is to be done. To make many tests in one day or to store identical samples in any quantity becomes a burden, if they are too heavy.

C. J. Fechheimer: The methods which have been described this evening for testing iron are applicable principally to transformers, in which the distribution of flux is very similar to that which obtains in the samples. They cannot, however, be used directly in dynamos or motors because in these there are heavy pulsations of flux and the distribution of flux in the core is by no means uniform and is quite different from that which we generally assume. The rapid change of flux which takes place when the edges of the poles pass under the armature teeth (or the armature teeth pass under the poles, whichever the case may be) also materially affects the loss occurring in the teeth. The result is that the core loss is two or three times as great as we would determine ordinarily by the constants obtained from transformer tests.

One of the speakers said this evening that the tests made in the factory on samples of new grades of steel are used for laying out a new line of machines. This, I believe, should be the case to a limited extent only, but I would be inclined to question it, because the transformer tests are not necessarily indications of what may be expected when the same steel is used in the armature cores of generators or motors.

For example, we know that while silicon steel has an eddy current loss, measured by means of transformer tests, which is considerably less than that of common steel and has also a slightly lower hysteresis loss, yet this steel does not have any appreciably less loss in generators or motors than the common steel. I questioned the results of the tests for sometime and had them repeated and was finally convinced when the temperatures indicated that the core loss as measured was correct.

There were six turbo generators of a certain size built, three with silicon steel and three with common steel, and the loss seemed to be about the same in all cases. There was, of course, some slight variation, but this variation was not any greater than that which usually occurs in duplicate machines built with the same quality of iron. I have never been able to account for this discrepancy and I should very much like to have an expression of opinion from some of the members to help clear this up.

Then there is another point which we find in practice does not

Digitized by Google

agree with theory. We usually assume, and without doubt correctly, that the eddy current loss varies with the square of the frequency and the square of the induction density. The hysteresis loss varies with the first power of the frequency and approximately with the 1.6 power of the density. However, I have found that the total core loss in machines varies from 1.9 to 2.2 power of the density, which would indicate that all the loss is due to eddy currents. Nevertheless when we compare the loss at different frequencies on the same machine we find that the loss is proportional to about the 1.4 power of the frequency, which would indicate that a great deal of the loss is due to hysteresis. This is another discrepancy for which I have never been able to account.

I should like to ask Professor MacLaren whether the iron did not age when starting with 25 cycles, repeating the tests at 60 cycles and then going back to 25 cycles. It would seem that the alternate heating and cooling of the samples causes the constants for the losses to be affected; that is, the iron would have aged.

C. A. Adams: At the recent mid-year convention at Schenectady, Mr. W. J. Wooldridge presented experimental data showing that the exponent of "B" in the Steinmetz formula for hysteresis loss was not a constant for modern silicon steels, but varied from about 1.5 at low densities up to 2.5 or more at high densities. The results of Prof. MacLaren's experiments seem to show that up to the highest density used by him, the exponent was 1.6 and practically constant throughout.

It is certainly very desirable that this apparent discrepancy be explained, for if both exponent and coefficient vary over a wide range, the Steinmetz law is not applicable to silicon steels.

W. S. Franklin: If the engineers concerned in making measurements would make a distinction between and use two distinctly different words for the two classes of errors, it would help us very much in regard to discussions of measurements of such things as hysteresis loss in iron. There are two distinct kinds of errors which physicists recognize, namely, errors due to the wabbling of the measuring instrument, and errors due to the inherent lack of constancy or definiteness of the thing you measure; and I think we should call the first of these errors, speaking of the probable error of a set of observations; that is, the things which are inherent in our methods and instruments, and the other things we should call departures. We could speak of "probable departures", etc. Take, for example, the main load factor of the consumer of electric lights who has fifty lights installed. We will say that the main load factor of that kind of a customer is 60 per cent. Now, as a matter of fact, there are enormous departures from that. If you were to take a large number of individual cases, you could determine what the probable departure is, for that probable use, if used in the same sense as we use probable errors. I wish we could get into the

Digitized by Google

habit of distinguishing clearly these two kinds of errors which enter into numerical measurements; one is external error and the other is internal error, and we might call one " error " and the other " departure ".

Malcolm MacLaren: In answering Mr. Sharp's question, regarding the use of iron wire, I would say that that was taken as a matter of convenience. It did not seem as though copper would be suitable to stand the high temperatures, and iron was the most convenient substitute. The wire was about one-sixteenth of an inch away from the sample, No. 18 wire used, the turns being spaced about one-eighth of an in. apart, so that with the large cross section of the sample it would seem that the error due to the additional iron in the wire would not be considerable. If extreme accuracy was aimed at, it would be probably better to use some other material such as nickel.

As to the ease of manipulating the apparatus in making the loop, I believe that it will be found that taking men who have not made loops before, they will find it much easier to accommodate themselves to this manipulation of the resistance than to making the observations with the ballistic step by step method. As an indication of the flexibility of the method we recently took loops varying from an induction of about 200 B up to about 14,000 B, in which the only change required was to vary the resistance in the galvanometer circuit, so as not to take too many points in tracing the loop through its cycle.

As to the lack of agreement in the measurements by the loop method and the two-frequency method, I can not explain slight discrepancies that occur except to say that at the lowest induction where the greatest discrepancy occurs the wattmeter deflection was too small to read accurately. I believe that the results presented by Mr. Robinson this evening are certainly a sufficient justification for the use of the two-frequency method in making such measurements.

Dr. Northrup speaks of the number of observers required to make the loop measurements. The loops presented in the paper were taken with two observers, it is a little easier, however, to have three, one to take the time, and read the ammeter, one to change the resistance, and the third to read the galvanometer.

Mr. Chubb speaks of the losses that would occur in the use of iron wire, but I think these have been largely eliminated by the use of the second coil which avoids the necessity of correcting for the $I^2 R$ loss and for the $I R$ drop. In addition, the currents were kept very low throughout the experiment, so that the distorting effect was small.

With regard to the change in permeability, this was not observed with any particular care. It was noted, however, that the change at the higher inductions was very small, until the higher temperatures were reached. Above 650 or 700 deg. cent., the permeability fell off very fast.

In reference to Mr. Fechheimer's question regarding the

Digitized by Google

method of making the measurements, the temperature was not allowed to fall at any time during the measurements, it was simply held constant for a sufficient time to take a set of readings, first at 25 cycles, then at 60 cycles, and then a few check readings at 25 cycles, so that the check readings would generally be taken less than ten minutes later the original readings. The sample was then allowed to heat up to the next point.

With reference to Dr. M. G. Lloyd's method of deriving values for the exponent of B in the expression for hysteresis loss, $w = a\,B^x$ I would say that the usually accepted interpretation of this expression is that the hysteresis loss in any magnetic material may be represented by a *constant* multiplied by the induction raised to an unknown power. If however the exponents given by Dr. Lloyd be used for the determination of a its value is found to be variable even with constant temperature. For example, using his figures in Table II for 218 deg. cent. a varies from 0.635×10^{-6} to 1.49×10^{-8}. These revised tables which he presents appear therefore to have no physical significance. My reason for taking 1.6 as the value of the exponent at the lower inductions was that these samples were admittedly not as advantageously designed for obtaining extreme accuracy as would have been possible if the windings had not been arranged to stand temperature up to 800 deg. cent. and numerous other investigators had obtained this value for ordinary steel at inductions near 6000 B. Also the results that had been published upon silicon steel while not entirely convincing indicated that this value of 1.6 was correct for inductions near 8000 B.

With regard to the possible effect of eddy currents in the determination of the hysteresis loop I would call attention to the fact that the samples were well laminated and that the time of reversal was over five minutes so that the eddy current could not be large. It was possible however to detect their presence and estimate their effect by holding the magnetizing current constant for a few moments during a reversal and noting the galvanometer deflection. The correction due to this cause could not well amount to more than the width of the line bounding the loop.

L. T. Robinson: With reference to the points that have been brought up about the variation of the hysteresis exponent, it was certainly very interesting to see that Professor MacLaren got the original 1.6 power results, whereas some of the rest of us have got something quite different. Whether the explanation is that which Mr. Chubb gave, that there may be certain irregularities in the tests which Professor MacLaren made, and we are right, or that the 1.6 is right and we are wrong, I do not know, but I think that is something that perhaps can be straightened out within a short time, at least I hope so. I have a great many results, and I am trying to work them up now and see if I can make anything out of them.

About the ballistic method, and the agreement, etc., between

Digitized by Google

the two methods of measurement, I think I covered that in a fair way in my paper. I do not know whether it should agree, or whether it should not agree. There are so many things about the behavior of iron in magnetic fields that we do not know, that I do not think we should be too positive about our statements. I am satisfied to say that we usually have looked on the ballistic method as a good way to make the test. It was the standard method, and in developing another method we simply looked back to the old method to see how it agreed. There is a fairly good agreement, whether it means anything or not, I do not want to say. I hope it does, but we are not by any means sure of it, until such time as we can explain some of the vagaries with reference to the separation for eddy currents at different densities. The whole thing is founded on certain assumptions, some of it I hope is true. They all of necessity cannot be true. If you start in to discuss the whole subject and proceed to the final analysis along known lines, you cannot go very far. You assume that the eddy current loss varies as the square of the frequency. When you say that you say that it varies as the square of the voltage produced. When you say that it varies as the square of the density, you say the same thing, but still when you try to separate using various densities, it does not work. You cannot separate by change in density, although you can separate and get a straight line by changing frequency. Whether the fact that you get the straight lines means that you get the correct result or not, I think we can by no means be sure we are correct in saying. There is an opportunity for something to be said about this subject that has some definiteness about it that our present statements must lack, because of our want of absolute knowledge.

With reference to the long period D'Arsonval galvanometer, with considerable damping, old and new are only comparative words, I would say that we have used such an arrangement since 1898, to the best of my recollection, and I believe it to be good.

The Koepsel apparatus referred to is perhaps not directly connected with the subject matter of the evening.

I believe that it was brought out first in this country and published in the *Electrical World* some time in 1894. It is said to have been brought out sooner than that by the one whose name is now applied to it—but I think it was not published until some time after.

With reference to using insulation between the sheets, I think it is not necessary to insulate alloy iron but it may be necessary to insulate standard sheets.

I believe Dr. Sharp spoke of the disagreement between tests made by another method and by the apparatus that has been developed by the Bureau. My remarks on the elegance of that method were based almost entirely on the results that were obtained with it regardless of the comparison with other results —that is, it seems to be very good, because they get very nice

Digitized by Google

separations, and the things that vary more in other apparatus seem to vary less in it, and therefore I thought it was very good.

I think the matter of the standard sample has been quite generally referred to as being desirable. I was much interested in Dr. Northrup's remarks about the transformer running at 200 deg. cent.—we may have something like that some time, but the most interesting thing is what would he use for the insulation. That information is somewhat incomplete.

With reference to Dr. Franklin's remarks about errors and departures, I think that is a very good distinction, but it is hard to tell which is which. You do not get anything just right—sometimes you know you are wrong, but do not know whether it is an error or a departure.

With reference to Mr. Chubb's remarks, there is nothing more than a slight difference of opinion on what seems to be a minor point. I appreciate the fact that results can be obtained accurately by the method that he prefers. I may be wrong in thinking so, but it seems to me it is better to do something that is more generally applicable than to choose some arrangement for matching one error against another in a specific device. However, the specific point brought up as it relates to any apparatus except that described in the paper I have not covered experimentally, and cannot, therefore, be very definite in expressing an opinion on it at this time.

With reference to Mr. Fechheimer's remarks, it is interesting to know that some one has found some things that he cannot explain. We have been finding them right along, and it would be very easy to write a paper on the things about iron that you have tried and seen, and could not explain.

Henry Pikler: We are engineers, ultimately interested in the performance of sheet steel in the finished apparatus. If different makes of electrical machinery were built of exactly the same quality of sheet steel, we would find that the total iron loss per pound of sheet steel in these machines would not be the same, although the magnetic densities and frequencies are kept the same. This is due to differences in the design and construction between the electrical machinery of the various makers. In other words, if a given quality of sheet steel be used for building the transformers of makers " A ", " B " and " C ", we would find that the total watts loss per pound, at the same magnetic density and frequency, would be different in these three transformers. If instead of transformers we consider generators or induction motors, we would find that these differences would be much greater.

From this it follows that in order to foretell the total watts loss in the finished electrical apparatus, it is not sufficient to know only the core loss watts per pound in a sample of sheet steel tested by some standard method; the figure obtained by the standard method must be multiplied by a coefficient.

Digitized by Google

The difficulty lies in establishing a method of testing samples which can be used as a standard. I wish to emphasize that, for the reasons pointed out above, I do not consider that it is of primary importance at all that by the standard method physically accurate core loss watts per pound may be determined, but that by using this standard we should always get exactly the same result, whether the test is made by Peter, or by Paul, in the United States, in Japan, or in Germany. I would go even further and state that it is not a core loss—that is, a watt loss measurement—which is necessarily the criterion of the quality of the steel. To illustrate my point by a drastic example, I mean that if for instance a certain sample of steel, under the conditions created by the standard method, be struck and it vibrates say so many times per second and between this number of vibrations and the total watts loss there is a definite relation and finally *this* standard method can be exactly duplicated everywhere and at any time for the purpose of obtaining uniform results, then this method is more desirable than one which is based on watt measurements and gives not so uniform a result.

Probably the most important function of a standard method is to establish a basis in the transactions between the purchaser and supplier of sheet steel which excludes any chance of dispute. It is my opinion that there is a greater necessity for establishing a standard to this effect, one that gives uniformly correct results within say 2 per cent than to have this method for the purpose of enabling the designer to predict the core loss in his machine within that limit. Because I consider the uniformity of the results the most important, I naturally do not favor the introduction of any element into the standard method which is liable to introduce variations. For this reason I am very strongly opposed to any method of testing iron for the above purposes for core loss where the magnetic circuit of the test piece is broken by joints of any kind.

In reference to several remarks and questions brought up in connection with " core loss ", which pointed out that the core loss of induction motors or turbo generators, etc., cannot be predicted, and furthermore the relations between watts, magnetic density and frequency do not follow the law given by the equation $W = M\ (B \backsim)^2 + NB^{1.6} \backsim$, I wish to give my opinion as follows:

In order to investigate these problems the engineer must become a physicist. Unfortunately, according to my observation, very few become such in their investigations. One of the most fundamental principles of physical investigation consists in attacking the problem step by step and these steps should be extremely small. A phenomenon, as it appears to us at first glance, is in reality a complexity of very many phenomena and we will not be able to understand the whole if we fail to recognize the details.

Take the simplest electromagnetic apparatus, the trans-

Digitized by Google

former. There the engineer assumes a uniform flux density as the underlying basis of his calculations, derived from the terminal voltage, frequency, number of turns and the dimensions of the core. The truth, however, is that in any commercial transformers, even with the best magnetic joints, such is not the case. The magnetic flux is the densest at the magnetic center, which is the center of the magnetizing winding and there the volts per turn are also the greatest. In either direction, away from this center, the density of the magnetic flux, and with it the induced electromotive force per turn of the winding, will diminish. Whereas in the neighborhood of the magnetic center the lines of force travel in the same direction as is the direction of the "mechanical" magnetic circuit in that region, in the neighborhood of the joints there will be many lines of force which will depart from the steel and will cut it transversely. Right at the joints this transverse cutting of the plates by the lines of force leaving them will be a maximum. This will introduce additional losses in the steel, mainly eddy losses, the magnitude of which depends upon the perfectness of the joint and the distribution of the winding over the core.

In considering, instead of a closed magnetic circuit of a transformer, the magnetic circuit of a generator or motor, we find the situation much more complicated. In these machines the irregular distribution of the magnetic flux is established even on purpose (low regulation, small slip, etc.). In these machines the transverse cutting of the core plates by the magnetic flux is very greatly pronounced. It is therefore a great mistake to expect to derive any conclusions as to core loss watts from measurements based on conditions where the magnetic flux travel in the direction of the mechanical magnetic circuit. Before trying to establish a relation between watts core loss and magnetic density derived from impressed or induced e.m.fs., turns and frequency, it is of primary importance to investigate the geometrical configuration of the path of the magnetic flux. This can be done either by exploring coils, or even by simple reasoning, based on experience, going step by step over the entire magnetic circuit and predicting the probable path of magnetism in order to get the geometrical configuration of the lines of force.

When we look at magnetic circuits, flux densities and core losses in this light, I think we shall be surprised to hear anybody expect a connection between core loss and magnetic density as derived from volts impressed, turns, etc.

M. G. Lloyd: It is highly desirable that some method of measuring hysteresis suitable for commercial conditions should be standardized in this country, for the convenience of manufacturers and buyers. The American Institute of Electrical Engineers could well take the initiative in this matter, as has been done by its sister society in Germany. There the Epstein method has been adopted and seems to give general satisfaction,

Digitized by Google

the standard test being at 50 cycles and 10,000 gausses. Perhaps the details of the Epstein method could be revised so as to be more acceptable in this country, but its predominant features should be retained for a standard comparison method. Where shop conditions make other methods desirable, they can of course be used, the standard method being resorted to only for occasional comparisons, and to check up results against those obtained by outside parties. The more accurate methods available by the use of properly proportioned rings or such apparatus as that in vogue at the Bureau of Standards are more especially suitable to investigations aimed at a correct value of the physical constants, and similar tests where accuracy is more important than economy in time, in materials or in the necessary apparatus. It is important, however, that any method adopted as a commercial standard should use a specimen of such dimensions that the hardening effect of the cut edges is small, since it is not always feasible to anneal after cutting, and indeed, unless annealing can also be standardized (a difficult matter), results obtained by different observers at different places would not be comparable. It is well recognized that the process of annealing is quite as important a factor in determining the properties of the material as any other factor involved. It is desirable also that the method should be adapted to the use of portable measuring instruments. This requires the use of a large sample, and it suggests the use of a good magnetic circuit in order to keep a fairly high power-factor. The Epstein method seems to have best met conditions generally found, but where it is necessary to make a large number of determinations in a short time, such a method as that described by Mr. Robinson is decidedly superior for the workshop. It gives comparative values with sufficient accuracy and has the advantage of using less time and material.

It is to be regretted that Mr. Robinson has said nothing about the application of his method to silicon-steel. Silicon-steel is usually used at higher flux densities than ordinary steel, and at the higher flux densities it requires a much larger magnetizing current, making a lower power-factor. In Mr. Robinson's method the magnetizing current must be large enough to induce the flux at the center of the specimen, and this may be 40 per cent higher than the nominal value of flux. The conditions are therefore much less favorable with silicon-steel than with ordinary steel.

The paper by Professor MacLaren is of great interest in showing the manner in which hysteresis varies with temperature. Caution should be observed, however, in attaching too much weight to the accuracy of his measurements. When the form-factor is not determined in the wattmeter method the results must be viewed with suspicion. Evidently the form-factor was not determined in these experiments. Even supposing that the voltage wave of the generator was sinusoidal, it is not likely

Digitized by Google

that the secondary electromotive force, whose form-factor enters into the computation of flux density, would have the assumed value. This is especially true since iron wire was used in the magnetizing coil and its resistance was probably high therefore, and moreover variable with temperature. Since the voltage used and the resistance of this winding are not given, it is impossible to judge of the amount of distortion probably present.

The values given for the exponents which represent the power of flux density which is proportional to the hysteresis are very misleading. In the first place they depend upon the assumption of 1.6 for one condition, and a computation based on this value for the other conditions. Moreover a very undesirable method has been used in making the computation. As a matter of fact the exponents vary through a wide range, from values less than unity to as high as 1.99, as will be seen in the accompanying tables, which have been computed for specimens two and three. In fact, at a temperature of 700 deg. the value is actually negative for silicon-steel, since it is to be observed that the hysteresis found at 8,000 gausses is greater than the value found at 10,000 gausses.

Professor MacLaren has computed his values by assuming 1.6 at the lowest flux density and used this value to determine the constant a, and the resulting value for a is used in computing the exponents for all other flux densities. In the tables which I have computed the exponent is found by means of the equation

$$x = \frac{\log w_1 - \log w_2}{\log B_1 - \log B_2}$$

and the value of the exponent therefore depends only upon the values found for the hysteresis at two values of flux density and the coefficient a is assumed to be constant only between these two points.

In the tables each value applies to the range of flux density between the value which it is opposite and the next preceding value. It will be seen from these tables that there is no regular variation in the value of the exponent, except that for silicon-steel at all but the highest temperatures the exponent decreases with increasing flux density. This result is in contradiction to most of the other experiments which have been made; most observers have found it to vary in the opposite direction. Reference may be made, for instance, to the paper by Mr. Wooldridge, at the Schenectady convention. As experience in this work has shown me what large errors may be produced in the result by small variations in the form-factor, it seems likely that these results are not very accurate and they are principally valuable in showing the general trend of hysteresis loss with temperature. In this connection it should be remembered, too, that at high flux densities the permeability decreases with increasing tempera-

Digitized by Google

ture. The magnetizing current would therefore increase and at the same time the resistance of the magnetizing circuit is increasing, so that the distortion would increase at a rapid rate.

The table given in the paper, showing the variation in induction with change in magnetizing current near the recalescence point, is chiefly valuable in showing the great rapidity of variation in that region. The differences found with ascending and descending temperatures are not significant. The two curves start very sharply at the same temperature of 737 deg. and cross at about 721 deg. An error in the measurement of temperature of three deg. would account for any difference found between these points. Since the variation of permeability with temperature is very different for different magnetizing forces, it is necessary to use a wide range of magnetizing forces to make such experiments of much value.

It is interesting to observe that the method used by Professor MacLaren for hysteresis loops can be used with small samples, as it has been generally supposed that this method was only applicable to cases in which the cross-section of the material, and consequently the flux, was very large. This method can hardly be claimed to have the accuracy, however, of the step-by-step method. Since the continuous change in flux will induce eddy currents which continue during the entire half loop, and since they oppose the main magnetizing field, the observed value of H will be too large. The extreme points of the loop will be correctly found, since the current becomes constant at these two points, but in between them the loop will be broadened, and the value for hysteresis will be too large. The result is similar to that found by the wattmeter method in a case where the eddy currents are small and are neglected. It is to be noted that in two of the three cases given, the loss is larger by this method than by the two-frequency method, although in the third case it is smaller by five per cent.

Dr. Sharp has called attention to the recent paper in the PROCEEDINGS of the Institution of Electrical Engineers in which the method used at the Bureau of Standards was reported to give results too high. I should like to call attention to the fact that the comparison was not made with the Epstein method, but with a different method whose accuracy was entirely unknown, although it was used as a standard of comparison. The only value of that research is in showing the differences found in the two methods.

It is sometimes wondered by those designing and testing electric machinery that the values of the exponents of flux density which are found in laboratory experiments, or computed on theoretical grounds, do not apply in practice. It would really be more wonderful if they did. Such an exponent as 2.0 for eddy currents, for instance, is computed on the assumption of uniform density in one definite direction in a sheet of infinite width. In dynamo and motor cores none of these conditions

Digitized by Google

are fulfilled, and even in transformer cores we do not have uniform flux density. The demagnetizing effect of the eddy currents makes the flux less at the center than near the surface. With increasing flux density or increasing frequency this effect is intensified and results in the eddy currents increasing at a less rate than the square of either of these quantities. As shown in Mr. Wooldridge's paper at the recent Schenectady convention, the exponent for eddy currents is actually found to decrease with increasing flux density, and such a decrease is qualitatively explained by the above consideration. It must be remembered, however, in connection with the determination of eddy-current losses, especially in silicon-steel, that they form a small part of the total loss, and accurate determinations are extremely difficult. Small errors in observation, or small departures in the wave form, may produce large errors in the value of exponent found.

In the cores of generators and motors, the flux density does not simply alternate in direction, and the relative distribution of flux is not constant. The flux pulsates in space as well as time. The laws of hysteresis and eddy-current loss which obtain with the usual testing apparatus cannot be expected to apply even approximately under such conditions.

TABLE II

B	Temperature in deg. cent.							
	218	237	358	445	527	597	660	707
6000								
8000	1.53	1.60	1.64	1.63	1.77	2.08	1.92	1.99
10000	1.87	1.68	1.68	1.69	1.70	1.54	1.57	1.25
12000	1.81	1.72	1.60	1.61	1.62	1.24	0.85	0.94
14000	1.94	1.72	1.62	1.38	1.31	1.14	1.41	0.60

TABLE III

B	Temperature in deg. cent.					
	47	300	402	508	597	659
8000						
10000	1.79	1.66	1.48	1.04	0.74	0.52
12000	1.68	1.44	1.36	0.96	0.60	1.425
14000	1.54	1.37				

J. D. Ball: In regard to the iron tester for 10 kg. samples 50 cm. by 3 cm., it might be well to add some data as to how satisfactory it has proven in actual practice. Regular checks are made between three laboratories: one located at the steel mill,

Digitized by Google

one at the transformer factory and one the standardizing laboratory.

The average of 278 samples teste d at the mill and factory agree within 1 per cent, the maximum variation of any one sample between the mill and factory measurements was 3.5 per cent. 100 samples tested at a later date show an agreement within 1/20 of one per cent of the same average loss measured in the two places.

Samples tested in all three laboratories show conclusively that average results are well within 1 per cent.

These comparisons are extremely good in as much as the mill test results quoted are results of single observations; the results given at the other points are, in many cases, the average of several observations.

There is one advantage in quoting results as hysteresis loss, as is done when tests are made on the small set (using 1 lb. sample 10 in.x $\frac{1}{2}$ in.) It has been demonstrated that the eddy current loss is a function of the kind, shape and thickness of material and geometrical construction of the test sample or transformer and is independent of total loss or manner of cutting sample as regards direction of rolling.

The hysteresis loss is a value to which may be added the eddy loss to give total core loss at any desired frequency for any size or shape of test sample or transformer after these eddy losses have been determined by separation tests on a comparatively few representative samples.

As is shown in the paper, this is true for the rings and other samples mentioned. It is also shown by Lloyd and Fisher (U. S. Bureau of Standards reprint 109) and other writers. The writer has found it true for various transformer cores of the same types and material.

Digitized by Google

DISCUSSION ON "ECONOMIC LIMITATIONS TO AGGREGATION OF POWER SYSTEMS", BOSTON, MASS., FEBRUARY 17, 1911. (SEE PROCEEDINGS FOR FEBRUARY, 1911.)

(Subject to final revision for the Transactions.)

A. E. Kennelly: The paper is of great interest, both theoretically and practically. It assumes the existence of not merely transmission system, but rather of a system of such systems; that is, it presupposes a network of transmission and absorption of power, including a plurality of generating and delivery stations.

In the ordinary transmission system of to-day, we are accustomed to regard the problem of electric pressure regulation as a corollary of the ordinary direct-current system. We expect to have a drop of pressure between the generating station and delivery station of not more than, say, 10 per cent of the delivery pressure, at rated load. This is a natural habit of thought derived from direct-current practice. In order to enable such a 10 per cent limit of drop to be maintained, the power-factor of the load may have to be restricted to a certain range, and condensive reactance may have to be supplied, with the aid of over-excited synchronous motors, in order to succeed.

If, however, a large number of transmisson and delivery lines spring up in any territory, it is evident that they must tend to coalesce; unless actually incompatible, so numerous and powerful are the engineering advantages to be gained by merging them into a single network. Having developed such a network, the complexity of maintaining assigned percentages of voltage drop on the lines, under various conditions of load, or of maintaining assigned percentages of power-factor, is likely to become excessive, and the old method of regarding the matter is therefore likely to become untenable.

The paper suggests that, under such conditions, much simpler conceptions and modes of operation are to be found in maintaining constant effective voltage at all station switchboards, and in ignoring the power-factors of the various loads, except in so far as these may indirectly have to be controlled in order to secure constant voltage. The idea is that no power-factor meters need appear on the various switchboards, and that the switchboard attendants shall regulate entirely for constant line-voltage.

In the paper reference is made to the fact that current may be made to flow in such a system from a point of lower to one of higher potential. This, of course, refers to effective, or r.m.s., potentials; because we know that, at any instant of time, current can only flow from a point of higher to a point of lower potential; but that, owing to difference of phase, the r.m.s. of the potential at the load may be greater than the r.m.s. of the potential at the generating point, taking the whole cycle of alternating potential into consideration.

We also know that all transmission lines necessarily possess

Digitized by Google

magnetic reactance. If a lagging current flows over such a line, the drop of r.m.s. pressure, as between generator and substation switchboards, becomes exaggerated. If, on the contrary, every distinctly leading current flows, the drop of pressure may be negative, or the r.m.s. pressure may be higher at the substation switchboard. As an intermediate condition, if the current leads moderately, the apparent drop of pressure may be made zero, and the voltage at both switchboards will thus be the same.

The paper, therefore, calls for a system of inter-connected stations such that every load may be a suitable leading load. This means that adjustable condensive reactance must be supplied at each substation. It will not do to have mere non-inductive loads. A pure resistance load—a simple lighting load—or a load of 100 per cent power-factor, will not suffice. There must be a definite amount of lead in the load. The power-factor must be less than 100 per cent and leading, so as to produce neither rise nor fall of voltage at the substation switchboard. Consequently, a synchronous motor, of adjustable excitation, to act as a condenser, must be available at each substation where power is delivered. If the load is a purely lighting load, very little over-excitation will be needed in the synchronous motor of the substation, in order to maintain the required lead of current-phase, for constant line voltage at the switchboard. If, on the other hand, a heavy inductive load, is delivered, such as an induction-motor load, correspondingly powerful over-excitation will be needed in the synchronous motor. Variations of load will thus call for variations of excitation, to keep the switchboard voltage steady.

If there were no magnetic reactance in the line wires, the method here under discussion of reducing the apparent line-drop to zero could not be used. The paper points out that, up to a certain point, the presence of reactance in the line is useful, for the purpose of maintaining uniform switchboard voltages over the entire system. It is intimated, in fact, that extra reactance, introduced into the lines, may thus benefit power transmission. Loading a telephone line with artificial reactance is well known to be beneficial in the case of electric telephone transmission. The analogy at once suggests itself that if loading a line with reactance is beneficial in alternating-current telephony, the same plan may also be beneficial in alternating-current power-transmission. It must be remembered, however, that the effect of loading a telephone line is to increase its tension. It reduces the effective current and increases the effective voltage of transmission, and so reduces the $I^2 R$ losses, in essentially the same way that increasing the voltage improves the economy of power transmission. This is very different from the effect here considered of loading a transmission line, and there is no proper analogy between the two cases.

A suitable amount of magnetic reactance in the lines of a large power-network is likely indeed to be useful, as indicated in the

Digitized by Google

paper, for limiting the violence of short-circuits, and the distance to which their injurious influences can extend; but it is questionable how far loading lines with reactance may be carried with advantage on other accounts. In a direct-current line of total resistance R ohms, a working current of I amperes will effect a drop of pressure of $I R$ volts, which must subtract from the generator voltage to give the substation voltage. In an alternating-current line of total impedance Z ohms, an effective working current of I amperes must similarly produce $I Z$ volts drop. The impedance Z must always exceed the ohmic resistance and may greatly exceed it if there is much reactance in the line. Now, as shown in the paper, it is possible to swing the $I Z$ drop into such phase relation to the generator-end voltage, that the vector difference, or receiving station voltage, may be numerically equal to the generator end voltage; but the greater the $I Z$ drop, the greater will be the changes of voltage that variations of load will tend to effect; or, to express the same condition in another way, the closer and more cared for will be the adjustment of leading current and condensive reactance that the synchronous motor must produce. Moreover, the greater the reactance in the system, the more powerful the surge overvoltage in the system that a given disturbance will set up. Consequently, the principle of the benefit derivable from extra reactance in such a system should be received with caution.

The author of the paper is to be complimented upon the very interesting and beautiful geometrical theorems which he presents in the supplement. These theorems are restricted to the limitation, laid down as a postulate, that constant voltage is maintained at the stations on the line. If this condition is departed from a considerable deviation may be involved in the conclusions, in some practical cases. But, from a theoretical standpoint, and within this limitation, the results deduced are very interesting.

It is to be regretted that in a paper which bids fair to be long remembered, the term " wattless power " is employed. This criticism is directed solely to language used, and not to the facts which the language is intended to express. The term " reactive power " would be just as easily understood, and would give rise to no self-contradiction in terms, besides avoiding ambiguity. Reactive volt-amperes in an alternating current system are just as " wattful " as the volt-amperes that are delivered and recorded through time, on the watt-hour meters; except that the reactive power is developed in displacing energy within the system from one part of the system to another; while the delivered power is developed in displacing energy from inside the system to the consumer's apparatus outside the system. Delivered power is saleable, and reactive power is not saleable; but the commercial distinction should not interfere with the terms and concepts of the matter, as they are reflected in the mind of the engineer.

Digitized by Google

N. T. Wilcox: The cheapening of hydraulic development due to the lesser cost and large production of Portland cement and the ability to transmit successfully at voltages of 100,000 or more have made things possible to-day that were impossible a few years ago. We even hear rumors of higher voltages than those mentioned.

It seems to me of prime importance that in the development of these propositions, efficient and competent engineering talent be employed. If these large plants are developed along wrong engineering lines, the resultant mistakes crystallize as a permanent tax on the whole development. We may be able to get rid of bad management, but are seldom able to get rid of the charges following a badly engineered development.

E. A. Ekern: The constant potential system as outlined in the paper by Mr. Philip is an ideal system as regards voltage regulation. To obtain this ideal voltage regulation it presupposes a sufficient and ample control of the power factor of the load at all of the various points on a transmission system.

With the continued growth of the high-tension transmission systems has developed a continual battle on the part of the engineers operating these systems to maintain a reasonable power factor which is essential to good voltage regulation. Until recently the tendency has been to attempt to improve the regulation by increasing the voltage. Except for the larger systems distributing large quantities of power to central points a limitation to the increase of voltage has been found in the corona loss from the small sizes of conductor and in the operating difficulty of charging the high tension lines which require a very large charging current and consequently a large current carrying capacity in the generating stations. In spite of the increased voltage of transmission of some of the long distance transmission systems until they are operating under the above conditions of corona loss and large charging currents many are experiencing difficulty in obtaining good voltage regulation on account of the low power factor resulting from the extensive use of the induction motor which predominates the field of small individual drive.

Many transmission engineers are turning their attention from the problem of increasing the voltage which has been solved quite satisfactorily and appears to have reached its present limitation for smaller systems, and are devoting their energies to improving the power factor and devising an equitable basis of charging for energy depending on the power factor of the load and its influence on the transmission system. This is being done to such an extent that it is now quite common practice to charge additional for energy of a load having a lagging power factor and placing a premium on energy of a load having a leading power factor. An excellent system for a rational basis of compensation according to the character of load was outlined by Professor Hooper at the last meeting of the Boston Section

Digitized by Google

held at Tufts College. This system consisted of not only metering and charging for the kw-hr. of energy but also metering and charging for the kw-hr. of wattless energy according as to whether it is lagging or leading.

If a system can be obtained which places a premium on a satisfactory power factor so that it will be found desirable to control the power factor at the various points of loading a high-tension transmission system it becomes quite possible to obtain the conditions as outlined in Mr. Philip's paper and the constant potential system will then be realized.

Edw. N. Lake: Two or three of the preceding speakers have appeared to be of the opinion that the paper this evening applies particularly to electrification problems. It seems to me that it has a very much broader application than the electrification of steam railroads. It involves, to my mind, all of the uses to which power may be applied and is a most daring conception—that of a high tension network covering the whole country just as a 250-volt or a 600-volt network serves a very limited territory.

Electrification of steam railways will never become general until two of the fundamental ideas of Mr. Philip's paper can be commercially applied; *viz.*, uniformity and interconnection. Transposing into railway language, uniformity becomes standardization, interconnection corresponds to interchange. Electrification cannot be made attractive to the railway man until standardization and interchange are positively assured to him.

R. P. Jackson: Mr. Philip's paper outlines a system of power transmission or rather of power traffic which is of unusual interest. The possibility of many or all power producers and users pooling their interests and supplying power to a common fund or drawing from this fund as it were, to meet their immediate needs is in the nature of a banking operation with electric power taking the place of funds.

One point of note, however, is that while *watts* may be the commodity exchanged the medium of exchange must properly be *voltamperes*.

While a customer who fails to supply his own lagging current may be automatically penalized by a drop in his supply voltage, yet his load may be such as not to suffer greatly from this cause while another customer adjacent in line connection may be inconvenienced by such drop. There is, moreover, to be considered the effect on generator capacity.

Consequently the system of metering must either register in volt-ampere-hours or preferably in two separate records, one of true power and the other of wattless ampere-hours. This would permit a system of premiums and discounts to be used, taking into account the quality of the medium of exchange.

According to the method of regulation given by Mr. Philip a more equitable system of metering might be to measure the power and the integrated volt-seconds of variation up or down from a standard line voltage.

Digitized by Google

Then either a power producer or a power user could be penalized for variations from the voltage of the system.

Metering devices to accomplish these results, however, are not now available so far as we are aware. Metering problems are even now rendered difficult by the question of maximum demand and limitation of peak loads, and the introduction of the necessity of taking account of apparent watts still further complicates the matter. The other advantages of the system described by Mr. Philip are such, however, that, should the commercial application of it demand, suitable metering methods and devices would doubtless be forth-coming.

Another feature of interest is that line reactance is no longer a disadvantage but on the other hand becomes a necessity. It is even suggested that artificial reactance in the form of choke coils be inserted in series with the line for the purpose of giving the greatest power carrying capacity to the line. Substantial choke coils such as are often used to protect against lightning and similar high frequency oscillations could then serve two purposes and cease to be looked upon with suspicion on account of the drop incurred.

Digitized by Google

Digitized by Google

STANDARDIZATION RULES OF THE A. I. E. E.

ADOPTED JUNE 27, 1911.

I. DEFINITIONS AND TECHNICAL DATA.

1 *Note*: The following definitions and classifications are intended to be practically descriptive and not scientifically rigid.

A. DEFINITIONS. CURRENTS AND E.M.F.'S.

2 A DIRECT CURRENT is a unidirectional current.

3 A CONTINUOUS CURRENT is a steady, or non-pulsating, direct current.

4 A PULSATING CURRENT is a current equivalent to the superposition of an alternating current upon a continuous current.

5 An ALTERNATING CURRENT OR E.M.F. is a current or e.m.f. which, when plotted against time in rectangular coördinates, consists of half-waves of equal area in successively opposite directions from the zero line.

5a CYCLE. Two immediately succeeding half-waves constitute a cycle.

5b PERIOD. The time required for the execution of a cycle is called a period.

5c FREQUENCY. The number of cycles per second is called the frequency.

5d WAVE-FORM. The shape of the curve of e.m.f. or current plotted against time in rectangular coördinates, is ordinarily referred to as the wave-form or wave-shape. Two alternating quantities are said to have the same wave-shape if their corresponding phase ordinates bear a constant ratio. The wave-shape, as ordinarily understood, is thus independent of the scales to which the curve is plotted.

5e SIMPLE ALTERNATING WAVE. Unless otherwise specified an alternating current or e.m.f. is assumed to be sinusoidal, and the wave a sinusoid, sine-wave or curve of sines. On this account a complete cycle is taken as 360 degrees, and any portion of a cycle may be expressed in degrees from any convenient reference point, such as the ascending zero-point.

5f A COMPLEX ALTERNATING WAVE is a non-sinusoidal wave. A complex alternating wave is capable of being resolved into a single sine wave of fundamental frequency, with superposed odd-frequency harmonic waves, or ripples, of 3, 5, 7 . . . $(2n+1)$ times the fundamental frequency, each harmonic having constant amplitude, and a definite starting phase-relation to the fundamental sine-wave. It is customary when analyzing a complex wave, to neglect harmonics higher than the 11th; *i.e.*, of frequency higher than 11 times the fundamental. In special cases, however, frequencies still higher may have to be considered. In certain exceptional cases even harmonics are present.

5g ROOT-MEAN-SQUARE VALUE (sometimes called the Virtual or Effective Value). Unless otherwise specified, the rating of an alternating-current or e.m.f., in amperes or volts, is assumed to be the square root of the mean square value taken throughout one or more complete cycles. This is sometimes abbreviated to r.m.s. The term root-mean-square is to be preferred to the terms virtual or effective. The root-mean-square value is indicated by all properly calibrated alternating-current voltmeters and ammeters. In the case of a sine-wave, the ratio of the maximum to the r.m.s. value is $\sqrt{2}$.

Digitized by Google

5h FORM-FACTOR OF AN ALTERNATING WAVE. The ratio of the root-mean-square to the arithmetical mean ordinate of a wave, taken without regard to sign, is called its form-factor. The form-factor for a purely rectangular wave is the minimum, 1.0; for a sine wave it is 1.11, and for a wave more peaked than a sine wave it is greater than 1.11.

5i THE EQUIVALENT SINE WAVE is a sine wave having the same frequency and the same r.m.s value as the actual wave.

5j The DEVIATION of wave-form from the sinusoidal is determined by superposing upon the actual wave, (as determined by oscillograph), the equivalent sine wave of equal length, in such a manner as to give the least difference, and then dividing the maximum difference between corresponding ordinates by the maximum value of the equivalent sine wave.

5k PHASE DIFFERENCE. When corresponding cyclic values of two sinusoidal alternating quantities such as two alternating currents or e.m.fs. or of a current and an e.m.f., of the same frequency, occur at different instants, the two alternating quantities are said to differ in phase, their phase difference being the time interval, expressed in degrees or as a fraction of a cycle, between the occurrence of their corresponding values; *e.g.*, their ascending zeros or their positive maxima.

5l EQUIVALENT PHASE DIFFERENCE. If two alternating quantities are non-sinusoidal, and of different wave shapes, the preceding definition of phase-difference is inapplicable, and phase-difference ceases to have exact significance. However, when the two complex alternating quantities are the voltage E and current I in a given circuit, the effective power P of which is known, it is customary to define the equivalent phase difference by the angle whose cosine is the power-factor, P/EI, of the circuit. See Sections 54 and 324.

5m SINGLE-PHASE. A term characterizing a simple alternating current circuit energized by a single alternating e.m.f. Such a circuit is usually supplied through two wires. The currents in these two wires counted positively outwards from the source, differ in phase by 180 degrees or half a cycle.

5n THREE-PHASE. A term characterizing the combination of three circuits energized by alternating e.m.fs. which differ in phase by one third of a cycle; *i.e.*, 120°.

5o QUARTER-PHASE, also called TWO-PHASE. A term characterizing the combination of two circuits energized by alternating e.m.fs. which differ in phase by a quarter of a cycle; *i.e.*, 90°.

5o SIX-PHASE. A term characterizing the combination of six circuits energized by alternating e.m.fs. which differ in phase by one sixth of a cycle; *i.e.*, 60°.

5o POLYPHASE is the general term applied to any alternating system with more than a single phase.

6 An OSCILLATING CURRENT is a current alternating in direction, and of decreasing amplitude.

B. DEFINITIONS. ROTATING MACHINES.

7 A GENERATOR transforms mechanical power into electrical power.

8 A DIRECT-CURRENT GENERATOR produces a direct current that may or may not be continuous.

9 An ALTERNATOR is an alternating-current generator, either single-phase or polyphase.

9a A SYNCHRONOUS ALTERNATOR comprises a constant magnetic field and an armature delivering either single-phase or polyphase current in synchronism with the rotation of the machine.

10 A POLYPHASE GENERATOR produces currents differing symmetrically in phase; such as quarter-phase currents, in which the terminal voltages of the two circuits differ in phase by 90 degrees; or three-phase currents, in which the terminal voltages of the three circuits differ in phase by 120 degrees.

Digitized by Google

11 A DOUBLE-CURRENT GENERATOR supplies both direct and alternating currents from the same armature-winding.

11a AN INDUCTOR ALTERNATOR is an alternator in which both field and armature windings are stationary.

11b AN INDUCTION GENERATOR is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

12 A MOTOR transforms electrical power into mechanical power.

12a A DIRECT-CURRENT MOTOR transforms direct-current power into mechanical power.

12b AN ALTERNATING-CURRENT MOTOR transforms alternating-current power into mechanical power.

12c A SYNCHRONOUS MOTOR is a machine structurally identical with a synchronous alternator, but operated as a motor.

12d A SYNCHRONOUS PHASE MODIFIER, sometimes called a Synchronous Condenser, is a synchronous motor, running either idle or under load, whose field excitation may be varied so as to modify the power-factor of the circuit, or through such modification to influence the voltage of the circuit.

12e AN INDUCTION MOTOR is an alternating-current motor, either single-phase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding has no conductive connection with the supply circuit.

12f A REPULSION MOTOR is an induction motor, usually single phase, in which the magnetic axis of the secondary, (a closed coil winding mounted on the rotor), is maintained at a certain fixed angle with respect to the stationary primary coil by means of a multisegmental commutator and short-circuiting brushes.

12g A SINGLE-PHASE SERIES COMMUTATOR MOTOR is structurally similar to a series direct-current motor, except that it is usually provided in addition with a series compensating winding distributed around the outer air-gap periphery and supported in slots in the pole faces, for the purpose of diminishing the armature leakage reactance.

13 A BOOSTER is a machine inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

14 A MOTOR-GENERATOR is a transforming device consisting of a motor mechanically connected to one or more generators.

15 A DYNAMOTOR is a transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

16 A CONVERTER is a machine employing mechanical rotation in changing electrical energy from one form into another. A converter may belong to either of several types, as follows:

17 *a.* A DIRECT-CURRENT CONVERTER converts from a direct current to a direct current, usually with a change of voltage.

18 *b.* A SYNCHRONOUS CONVERTER (commonly called a rotary converter) converts from an alternating to a direct current, or *vice versa*.

19 *c.* A MOTOR-CONVERTER is a combination of an induction motor with a synchronous converter, the secondary of the former feeding the armature of the latter with current at some frequency other than the impressed frequency; *i.e.*, it is a synchronous converter concatenated with an induction motor.

20 *d.* A FREQUENCY CHANGER converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases or in the voltage.

21 *e.* A ROTARY PHASE CONVERTER converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

21a EQUALIZING CONNECTIONS are low resistance connections between equipotential points of multiple-wound closed-coil armatures to equalize the induced voltage between brushes.

Digitized by Google

C. DEFINITIONS. STATIONARY INDUCTION APPARATUS.

22 STATIONARY INDUCTION APPARATUS changes electric energy to electric energy through the medium of magnetic energy. It comprises several forms, distinguished as follows:

23 *a.* TRANSFORMERS, in which the primary and secondary windings are insulated from one another.

23a A PRIMARY WINDING is that winding of a transformer, or of an induction motor, which receives power from an external source.

23b A SECONDARY WINDING is that winding of a transformer, or of an induction motor, which receives power from the primary by induction.

Note: The terms "High-voltage winding" and "Low-voltage winding" are suitable for distinguishing between the windings of a transformer, where the relations of the apparatus to the source of power are not involved.

24 *b.* AUTO-TRANSFORMERS, also called compensators, in which a part of the primary winding is used as a secondary winding, or conversely.

25 *c.* POTENTIAL REGULATORS, in which one coil is in shunt and one in series with the circuit, so arranged that the ratio of transformation between them is variable at will. They are of the following three classes:

26 1. CONTACT VOLTAGE REGULATORS, also called Compensator Regulators, in which the number of turns in use of one of the coils is adjustable.

27 (2) INDUCTION POTENTIAL REGULATORS in which the relative positions of the primary and secondary coils are adjustable.

28 (3) MAGNETO POTENTIAL REGULATORS in which the direction of the magnetic flux with respect to the coils is adjustable.

29 *d.* REACTORS or REACTANCE COILS, also called choke coils, are a form of stationary induction apparatus used to supply reactance or to produce phase displacement.

29a *e.* AN INDUCTION STARTER is a device used in starting induction motors, converters, etc., by voltage control, consisting of an auto-transformer combined with a suitable switching device.

29b A LEAKAGE REACTANCE or SERIES REACTANCE is a portion of the reactance of any induction apparatus which is due to stray or purely self-inductive flux.

D. GENERAL CLASSIFICATION OF APPARATUS.

30 COMMUTATING MACHINES. Under this head may be classed the following: Direct-current generators; direct-current motors; direct-current boosters; motor-generators; dynamotors; converters; compensators or balancers; closed-coil arc machines, and alternating-current commutating motors.

31 Commutating machines may be further classified as follows:

32 *a.* DIRECT-CURRENT COMMUTATING MACHINES, which comprise a magnetic field of constant polarity, a closed-coil armature, and a multisegmental commutator connected therewith.

33 *b.* ALTERNATING-CURRENT COMMUTATING MACHINES, which comprise a magnetic field of alternating polarity, a closed-coil armature, and a multisegmental commutator connected therewith.

34 *c.* SYNCHRONOUS COMMUTATING MACHINES, which comprise synchronous converters, motor-converters and double-current generators.

35 SYNCHRONOUS MACHINES, comprise a constant magnetic field, and an armature receiving or delivering alternating-currents in synchronism with the motion of the machine; *i.e.*, having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

36 STATIONARY INDUCTION APPARATUS, include transformers, auto-transformers, potential regulators, and reactors or reactance coils.

37 ROTARY INDUCTION APPARATUS, or INDUCTION MACHINES, include apparatus wherein the primary and secondary windings rotate with re-

Digitized by Google

spect to each other; *i.e.*, induction motors, induction generators, frequency converters, and rotary phase converters.

38 UNIPOLAR or ACYCLIC MACHINES, direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

39 RECTIFYING APPARATUS, PULSATING-CURRENT GENERATORS.

40 ELECTROSTATIC APPARATUS, such as condensers, etc.

41 ELECTROCHEMICAL APPARATUS, such as batteries, etc.

42 ELECTROTHERMAL APPARATUS, such as heaters, etc.

42a REGULATING APPARATUS, such as rheostats, etc.

42b SWITCHING APPARATUS.

43 PROTECTIVE APPARATUS, such as fuses, circuit-breakers, lightning arresters, etc.

44 LUMINOUS SOURCES.

E. MOTORS. SPEED CLASSIFICATION.

45 MOTORS may, for convenience, be classified with reference to their speed characteristics as follows:

46 *a.* CONSTANT-SPEED MOTORS, in which the speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

47 *b.* MULTISPEED MOTORS (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as motors with two armature windings, or induction motors with controllers for changing the number of poles.

48 *c.* ADJUSTABLE-SPEED MOTORS, in which the speed can be varied gradually over a considerable range; but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of field variation.

49 *d.* VARYING-SPEED MOTORS, or motors in which the speed varies with the load, decreasing when the load increases; such as series motors.

F. DEFINITIONS. INSTRUMENTS.

49a AN AMMETER is a current-measuring instrument, indicating in amperes.

49b A VOLTMETER is a voltage-measuring instrument, indicating in volts.

49c A WATTMETER is an instrument for measuring electrical power, and indicating in watts.

49d RECORDING AMMETERS, VOLTMETERS, WATTMETERS, etc., are instruments which record graphically upon a time-chart the values of the quantities they measure.

49e A WATT-HOUR METER is an instrument for registering total watt-hours. This term is to be preferred to the term " integrating wattmeter ".

49f A VOLTMETER COMPENSATOR is a device in connection with a voltmeter, which causes the latter to indicate the voltage at some other point of the circuit.

49g A SYNCHROSCOPE is a synchronizing device which, in addition to indicating synchronism, shows whether the machine to be synchronized is fast or slow.

G. DEFINITION AND EXPLANATION OF TERMS.

(I) *LOAD FACTOR.*

50 The LOAD FACTOR of a machine, plant or system is the ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day or a year, and the maximum is taken over a short interval of the maximum load within that period.

51 In each case the interval of maximum load should be definitely specified. The proper interval is usually dependent upon local conditions and upon the purpose for which the load factor is to be determined.

Digitized by Google

(II) *DIVERSITY FACTOR.*

51a DIVERSITY FACTOR is the ratio of the sum of the maximum power demands of the subdivisions of any system or part of a system, to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

(III) *DEMAND FACTOR.*

51b DEMAND FACTOR is the ratio of the maximum power demand of any system or part of a system to the total connected load of the system or of the part of system under consideration.

(IV) *NON-INDUCTIVE LOAD AND INDUCTIVE LOAD.*

52 A non-inductive load is a load in which the current is in phase with the voltage across the load.

53 An inductive load is a load in which the current lags behind the voltage across the load. A load in which the current leads the voltage across the load is sometimes called a condensive or anti-inductive load.

53a When voltage and current waves are sinusoidal but not in phase, the voltage may be resolved into two components one in phase with the current, and the other in quadrature therewith. The former is called the effective component (sometimes the energy component), and the latter the reactive component of the voltage. The current may be similarly subdivided with respect to the voltage, and the two components similarly named.

(V) *POWER-FACTOR AND REACTIVE FACTOR.*

54 The POWER-FACTOR in alternating-current circuits or apparatus is the ratio of the effective (*i.e.* the cyclic average) power in watts to the apparent power in volt-amperes. It may be expressed as follows:

$$\frac{\text{effective power}}{\text{apparent power}} = \frac{\text{effective watts}}{\text{total volt-amperes}} = \frac{\text{effective current}}{\text{total current}} = \frac{\text{effective voltage}}{\text{total voltage}}$$

55 The REACTIVE-FACTOR is the ratio of the reactive volt-amperes (*i.e.*, the product of the reactive component of current by voltage, or reactive component of voltage by current) to the total volt-amperes. It may be expressed as follows:

$$\frac{\text{reactive power}}{\text{apparent power}} = \frac{\text{reactive watts}}{\text{total volt-amperes}} = \frac{\text{reactive current}}{\text{total current}} = \frac{\text{reactive voltage}}{\text{total voltage}}$$

56 POWER-FACTOR and REACTIVE-FACTOR are related as follows:
If p = power-factor and q = reactive-factor, then with sine waves of voltage and current,

$$p^2 + q^2 = 1$$

With distorted waves of voltage and current, q ceases to have definite significance.

(VI) *SATURATION-FACTOR.*

57 The SATURATION-FACTOR of a machine is the ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. The saturation factor is, therefore, a criterion of the degree of saturation attained in the magnetic circuit at any excitation selected. Unless otherwise specified, however, the saturation factor of a machine refers to the excitation existing at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

58 The PERCENTAGE OF SATURATION of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is indepen-

Digitized by Google

dent of the scale selected for excitation and voltage. This ratio is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity. Thus, if f be the saturation-factor and p the percentage of saturation,

$$p = 1 - \frac{1}{f}$$

(VII) *VARIATION AND PULSATION.*

59 The VARIATION IN PRIME MOVERS which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 degrees.

60 The PULSATION IN PRIME MOVERS is the ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

61 The VARIATION IN ALTERNATORS or alternating-current circuits in general is the maximum difference in phase of the generated voltage wave from a wave of absolutely constant frequency of the same average value, expressed in electrical degrees (one cycle equals 360 degrees) and may be due to the variation of the prime mover.

62 The PULSATION IN ALTERNATORS or alternating-current circuits, in general, is the ratio of the difference between maximum and minimum frequency during an engine cycle to the average frequency.

63 RELATION OF VARIATION in prime mover and alternator. If p = number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and $p\,n$ times the variation of the prime mover if rigidly connected thereto in the velocity ratio n; so that the speed of the alternator is n times that of the prime mover.

II. PERFORMANCE SPECIFICATIONS AND TESTS.

A. RATING.

65 RATING BY OUTPUT. All electrical apparatus should be rated by output and not by input. Generators, transformers, etc., should be rated by electrical output: motors by mechanical output, and preferably in kilowatts.

65a The following four classes of rating are recognized and recommended: they do not cover the rating of railway motors which is treated in Appendix B, and there are other large though less definitely definable classes of service in which each case must be treated by itself. Some of these may be later reduced to fairly simple terms and introduced into these Rules.

65b 1. CONTINUOUS RATING in which under load there is the attainment of approximately stationary temperature, and no other limit of capacity is exceeded.

65c 2. INTERMITTENT RATING in which one minute periods of load and rest alternate until the attainment of approximately stationary temperature and no other limit of capacity is exceeded.

65d NOTE:—Since the temperature depends upon the losses and the capacity of the apparatus to emit them, a constant load may be substituted for the intermittent load in determining the temperature, provided the losses are equivalent.

65e 3. MINUTE RATING in which under load for one minute, no mechanical, thermal, magnetic, or electrical limit of capacity is exceeded and no permanent change is wrought in the apparatus.

65f 4. VARIABLE SERVICE RATING. It is desirable here to recognize this class of rating which is intended to cover the rating of motors for machine-tool and similar service, in which the thermal absorptive capacity plays a part. The specifications for this rating have not been fully determined at the time that this edition of the Rules goes to press.

Digitized by Google

66 RATING IN KILOWATTS. Electrical power should be expressed in kilowatts, except when otherwise specified.

67 APPARENT POWER, KILOVOLT-AMPERES. Apparent power in alternating-current circuits should be expressed in kilovolt-amperes as distinguished from effective power in kilowatts. When the power factor is 100 per cent, the apparent power in kilovolt-amperes is equal to the kilowatts.

68 The RATED (FULL-LOAD) CURRENT is that current which, with the rated terminal voltage, gives the rated kilowatts, or the rated kilovolt-amperes. In machines in which the rated voltage differs from the no-load voltage, the rated current should refer to the former.

69 DETERMINATION OF RATED CURRENT. The rated current may be determined as follows: If P = rating in watts, or volt-amperes if the power factor be other than 100 per cent, and E = full-load terminal voltage, the rated current per terminal is:

70 $I = \frac{P}{E}$ amperes, in a direct-current machine or single-phase alternator.

71 $I = \frac{1}{\sqrt{3}} \frac{P}{E}$ amperes, in a three-phase alternator.

72 $I = \frac{1}{2} \frac{P}{E}$ amperes, in a quarter-phase alternator.

73 NORMAL CONDITIONS. The rating of machines or apparatus should be based upon certain normal conditions to be assumed as standard, or to be specified. These conditions include voltage, current, power-factor, frequency, wave shape and speed; or such of them as may apply in each particular case. Performance tests should be made under these standard conditions unless otherwise specified.

74 *a.* POWER FACTOR. Since the inherent capacity of alternating current generators, synchronous motors, and transformers, depends upon their voltage and their current, they should be rated in kilovolt-amperes. If the apparatus is rated in kilowatts without specification as to the power factor, a power factor of 100 per cent shall be understood.

If rated in kilowatts and a power factor other than 100 per cent be specified, this should be understood as defining only the nature of the load, and not as implying an increase in the ampere rating of the apparatus, which should be based upon the kilowatt rating at 100 per cent power factor.

75 *b.* WAVE SHAPE. In determining the rating of alternating-current machines or apparatus, a sine wave shape of alternating current and voltage is assumed, except where a distorted wave shape is inherent to the apparatus. See Secs. 79–80.

76 FUSES. The rating of a fuse should be the maximum current which it will continuously carry.

77 CIRCUIT-BREAKERS. The rating of a circuit-breaker should be the maximum current which it is designed to carry continuously.

77a NOTE. In addition thereto, the maximum current and voltage at which a fuse or a circuit-breaker will open the circuit should be specified. It is to be noted that the behavior of fuses and of circuit-breakers is much influenced by the amount of electric power available on the circuit.

78 INDICATING METERS should be rated according to their full-scale reading of volts, amperes, or watts. In wattmeters the rated volts and rated amperes should also be included; *i.e.*, the volts and amperes which can be safely and continuously carried by the voltage and current coils respectively.

78a WATT-HOUR METERS should be rated in volts and amperes.

B. WAVE SHAPE.

79 The SINE WAVE should be considered as standard, except where a deviation therefrom is inherent in the operation of the apparatus

80 A MAXIMUM DEVIATION of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified. See Section 5j.

81, 82, 83. See Sections 5e to 5l.

Digitized by Google

C. EFFICIENCY.

(I) *DEFINITIONS.*

84 The EFFICIENCY of an apparatus is the ratio of its output to its input. The output and input may be in terms of watt-hours, watts, volt-amperes, amperes, or any other quantity of interest, thus respectively defining energy-efficiency, power-efficiency, apparent-power-efficiency, current-efficiency, etc. Unless otherwise specified, however, the term is ordinarily assumed to refer to power-efficiency. An exception should be noted in the case of luminous sources, (see Sec. 346).

86 APPARENT EFFICIENCY. In apparatus in which a phase displacement is inherent to their operation, apparent efficiency should be understood as the ratio of net power output to volt-ampere input.

87 *a.* NOTE. Such apparatus comprises induction motors, synchronous phase modifiers, synchronous converters controlling the voltage of an alternating-current system, potential regulators, open magnetic circuit transformers, etc.

88 *b.* NOTE. Since the apparent efficiency of apparatus delivering electric power depends upon the power-factor of the load, the apparent efficiency, unless otherwise specified, should be referred to a load power-factor of unity.

(II) *MEASUREMENT OF EFFICIENCY.*

89 METHODS. Efficiency may be determined by either of two methods, *viz.*: by measurement of input and output; or, by measurement of losses.

90 *a.* METHOD OF INPUT AND OUTPUT. The input and output may both be measured directly. The ratio of the latter to the former is the efficiency.

91 *b.* METHOD BY LOSSES. The losses may be measured either collectively or individually. The total losses may be added to the output to derive the input, or subtracted from the input to derive the output.

92 COMPARISON OF METHODS. The output and input method is preferable with small machines. When, however, as in the case of large machines, it is impracticable to measure the output and input; or when the percentage of power loss is small and the efficiency is nearly unity, the method of determining efficiency by measuring the losses should be followed.

93 ELECTRIC POWER should be measured at the terminals of the apparatus. In tests of polyphase machines, the measurement of power should not be confined to a single circuit but should be extended to all the circuits in order to avoid errors of unbalanced loading.

94 MECHANICAL POWER in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered, with constant speed, as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of separating them from those of the prime mover.

95 In AUXILIARY APPARATUS, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the principal machine, but to the plant consisting of principal machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

96 NORMAL CONDITIONS. Efficiency tests should be made under normal conditions herein set forth, which are to be assumed as standard. These conditions include voltage, current, power-factor, frequency, wave shape, speed, temperature and barometric pressure, or such of them as may apply in each particular case. Performance tests should be made under these standard conditions unless otherwise specified. See Secs. 73–75.

97 *a.* TEMPERATURE. The efficiency of all apparatus, except such as may be intended for intermittent service, should be either measured at, or re-

Digitized by Google

duced to, the temperature which the apparatus assumes under continuous operation at rated load, referred to a room temperature of 25 deg. cent. See Secs. 267–292.

98 With apparatus intended for intermittent service, the efficiency should be determined at the temperature assumed under specified conditions.

99 *b.* POWER FACTOR. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the voltage, unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, induction generators, frequency converters, etc.

100 *c.* WAVE SHAPE. In determining the efficiency of alternating-current apparatus, the sine wave should be considered as standard, except where a difference in the wave form from the sinusoidal is inherent in the operation of the apparatus. See Sec. 80.

(III) *MEASUREMENT OF LOSSES.*

101 LOSSES. The usual sources of losses in electrical apparatus and the methods of determining these losses are as follows:

102 (*A*) BEARING FRICTION AND WINDAGE.

The magnitude of bearing friction and windage (which may be considered as independent of the load) is conveniently measured by driving the machine from an independent motor, the output of which may be suitably determined. See Sec. 94.

(*B*) COMMUTATOR BRUSH FRICTION.

103 The magnitude of the commutator brush friction (which may be considered as independent of the load) is determined by measuring the difference in power required for driving the machine with brushes on and with brushes off (the field being unexcited).

(*C*) COLLECTOR-RING BRUSH FRICTION.

104 Collector-ring brush friction may be determined in the same manner as commutator brush friction. It is usually negligible.

(*D*) MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS.

105 These losses include those due to molecular magnetic friction and eddy currents in iron and copper and other metallic parts, also the losses due to currents in the cross-connections of cross-connected armatures.

106 In MACHINES these losses should be determined on open circuit and at a voltage equal to the rated voltage $+I\,r$ in a generator, and $-I\,r$ in a motor, where I denotes the current strength and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

107 NOTE. The TOTAL LOSSES in bearing friction and windage, brush friction, magnetic friction and eddy currents can, in general, be determined by a single measurement by driving the machine with the field excited, either as a motor, or by means of an independent motor.

108 RETARDATION METHOD. The no-load iron, friction, and windage losses may be segregated by the Retardation Method. The generator should be brought up to full speed (or, if possible, to about 10 per cent above full speed) as a motor, and, after cutting off the driving power and excitation, frequent readings should be taken of speed and time, as the machine slows down, from which a speed-time curve can be plotted. A second curve should be taken in the same manner, but with full field excitation; from the second curve the iron losses may be found by subtracting the losses found in the first curve.

109 The speed-time curves can be plotted automatically by belting a small separately excited generator (say 1/10 kw.) to the generator shaft and connecting it to a recording voltmeter.

(*E*) ARMATURE-RESISTANCE LOSS.

110 This loss may be expressed by $p\,I^2\,r$; where r = resistance of one armature circuit or branch, I = the current in such armature circuit or branch, and p = the number of armature circuits or branches.

Digitized by Google

(*F*) COMMUTATOR, BRUSH AND BRUSH-CONTACT RESISTANCE LOSS.

111 It is desirable to point out that with carbon brushes these losses may be considerable in low-voltage machines.

(*G*) COLLECTOR-RING AND BRUSH-CONTACT RESISTANCE LOSS.

112 This loss is usually negligible, except in machines of extremely low voltage or in unipolar machines.

(*H*) FIELD-EXCITATION LOSS.

113 With separately excited field, the loss of power in the resistance of the field coils alone should be considered. With either shunt- or series-field windings, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

114 (*I*) LOAD LOSSES.

The load losses may be considered as the difference between the total losses under load and the sum of the losses as above specified and determined.

115 *a*. In COMMUTATING MACHINES of small field distortion, the load losses are usually trivial and may, therefore, be neglected. When, however, the field distortion is large as in commutating-pole machines; or, as is shown, for instance, by the necessity for shifting the brushes between no load and full load on non-commutating pole machines; these load losses may be considerable, and should be taken into account. In this case the efficiency may be determined either by input and output measurements, or the load losses may be estimated by the method of Sec. 116.

116 *b*. ESTIMATION OF LOAD LOSSES. While the load losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short-circuit and at full-load current, that is, by determining what may be called the " short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

117 One-third of the short-circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

(IV) *EFFICIENCY OF DIFFERENT TYPES OF APPARATUS.*

(*A*) DIRECT-CURRENT COMMUTATING MACHINES.

118 In DIRECT-CURRENT COMMUTATING MACHINES the losses are:

119 *a*. BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

120 *b*. MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS. See Measurement of Losses (*D*), Sec. 105.

121 *c*. ARMATURE RESISTANCE LOSSES. See Measurement of Losses (*E*), Sec. 110.

122 *d*. COMMUTATOR BRUSH FRICTION. See Measurement of Losses (*B*), Sec. 103.

123 *e*. COMMUTATOR, BRUSH AND BRUSH-CONTACT RESISTANCE. See Measurement of Losses (*F*), Sec. 111.

124 *f*. FIELD EXCITATION LOSS. See Measurement of Losses (*H*), Sec. 113.

125 *g*. LOAD LOSSES. See Measurement of Losses (*I*), Sec. 114.

126 NOTE. *b* and *c* are losses in the armature or " armature losses "; *d* and *e* " commutator losses "; *f* " field losses."

(*B*) ALTERNATING-CURRENT COMMUTATING MACHINES.

127 In ALTERNATING-CURRENT COMMUTATING MACHINES, the losses are:

128 *a*. BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

129 *b*. ROTATION LOSS, measured with the machine at open circuit, the brushes on the commutator, and the field excited by alternating current when driving the machine by a motor.

130 This loss includes molecular magnetic friction and eddy currents, caused by rotation through the magnetic field, $I^2 r$ losses in cross-con-

Digitized by Google

nections of cross-connected armatures, I^2r and other losses in armature-coils and armature-leads which are short-circuited by the brushes as far as these losses are due to rotation.

131 *c.* ALTERNATING or TRANSFORMER LOSS. These losses are measured by wattmeter in the field circuit, under the conditions of test *b*. They include molecular magnetic friction and eddy-currents due to the alternation of the magnetic field, I^2r losses in cross-connections of cross-connected armatures, I^2r and other losses in armature coil and commutator leads which are short-circuited by the brushes, as far as these losses are due to the alternation of the magnetic flux.

132 The losses in armature-coils and commutator leads short-circuited by the brushes, can be separated in *b*, and *c*, from the other losses, by running the machine with and without brushes on the commutator.

133 *d.* I^2R Loss, other load losses in armature and compensating winding and I^2r loss of brushes, may be measured by a wattmeter connected across the armature and compensating winding.

134 *e.* FIELD EXCITATION LOSS. See Measurement of Losses (*H*), Sec. 113.

135 *f.* COMMUTATOR BRUSH-FRICTION. See Measurement of Losses (*B*), Sec. 103.

(*C*) SYNCHRONOUS COMMUTATING MACHINES.

136 1. In DOUBLE-CURRENT GENERATORS, the efficiency of the machine should be determined as a direct-current generator, and also as an alternating-current generator. The two values of efficiency may be different, and should be clearly distinguished.

137 2. In CONVERTERS the losses should be determined when driving the machine by a motor. These losses are:

138 *a.* BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

139 *b.* MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS. See Measurement of losses (*D*) Sec. 105.

140 *c.* ARMATURE-RESISTANCE LOSS. This loss in the armature is $q\,I^2r$, where I = direct current in armature, r = armature resistance and q, a factor which is equal to 1.47 in single-circuit single-phase, 1.15 in double-circuit single-phase, 0.59 in three-phase, 0.39 in two-phase, and 0.27 in six-phase converters.

141 *d.* COMMUTATOR-BRUSH FRICTION. See Measurement of Losses (*B*), Sec. 103.

142 *e.* COLLECTOR-RING BRUSH FRICTION. See Measurement of Losses (*C*), Sec. 104.

143 *f.* COMMUTATOR, BRUSH AND BRUSH-CONTACT RESISTANCE LOSS. See Measurement of Losses (*F*) Sec. 111.

144 *g.* COLLECTOR-RING BRUSH-CONTACT RESISTANCE LOSS. See Measurement of Losses (*G*), Sec. 112.

145 *h.* FIELD-EXCITATION LOSS. See Measurement of Losses (*H*), Sec. 109.

146 *i.* LOAD LOSSES. These can generally be neglected, owing to the absence of field distortion.

147 3. THE EFFICIENCY OF TWO SIMILAR CONVERTERS may be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct-current input and the direct-current output. This process may be modified by returning the output of the second machine through two boosters into the first machine and measuring the losses. Another modification is to supply the losses by an alternator between the two machines, using potential regulators.

(*D*) SYNCHRONOUS MACHINES.

148 In SYNCHRONOUS MACHINES the losses are:

149 *a.* BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

150 *b.* MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS. See Measurement of Losses (*D*), Sec. 105.

Digitized by Google

151 *c.* ARMATURE-RESISTANCE LOSS. See Measurement of Losses (*E*), Sec. 110.

152 *d.* COLLECTOR-RING BRUSH FRICTION. See Measurement of Losses (*C*), Sec. 104.

153 *e.* COLLECTOR-RING BRUSH-CONTACT RESISTANCE LOSS. See Measurement of Losses (*G*), Sec. 112.

154 *f.* FIELD-EXCITATION LOSS. See Measurement of Losses (*H*), Sec. 113.

155 *g.* LOAD LOSSES. See Measurement of Losses (*I*), Sec. 114.

(*E*) STATIONARY INDUCTION APPARATUS.

156 In STATIONARY INDUCTION APPARATUS, the losses are:

157 *a.* MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS measured at open secondary circuit, rated frequency, and at rated voltage $-I\,r$, where I = rated current, r = resistance of primary circuit.

158 *b.* RESISTANCE LOSSES, the sum of the $I^2\,r$ losses in the primary and in the secondary windings of a transformer, or in the two sections of the coil in a compensator or auto-transformer, where I = rated current in the coil or section of coil, and r = resistance.

159 *c.* LOAD LOSSES, *i.e.*, eddy currents in the iron and especially in the copper conductors, caused by the current at rated load. For practical purposes they may be determined by short-circuiting the secondary of the transformer and impressing upon the primary a voltage sufficient to send rated load current through the transformer. The loss in the transformer under these conditions, measured by wattmeter, gives the load losses $+I^2\,r$ losses in both primary and secondary coils.

160 In CLOSED MAGNETIC CIRCUIT TRANSFORMERS, either of the two circuits may be used as primary when determining the efficiency.

161 In POTENTIAL REGULATORS, the efficiency should be taken at the maximum voltage for which the apparatus is designed, and with non-inductive load, unless otherwise specified.

(*F*) ROTARY INDUCTION APPARATUS, or INDUCTION MACHINES.

162 In ROTARY INDUCTION APPARATUS, the losses are:

163 *a.* BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

164 *b.* MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS in iron, copper and other metallic parts; also $I^2\,r$ losses which may exist in multiple-circuit windings. *a* and *b* together are determined by running the motor without load at rated voltage, and measuring the power input.

165 *c.* PRIMARY $I^2\,R$ LOSS, which may be determined by measurement of the current and the resistance.

166 *d.* SECONDARY $I^2\,R$ LOSS, which may be determined as in the primary, when feasible; otherwise, as in squirrel-cage secondaries, this loss is measured as part of *e*.

167 *e.* LOAD LOSSES; *i.e.*, molecular magnetic friction, and eddy currents in iron, copper, etc., caused by the stray field of primary and secondary currents, and secondary $I^2\,R$ loss when undeterminable under (*d*). These losses may for practical purposes be determined by measuring the total power, with the rotor short-circuited at standstill and a current in the primary circuit equal to the primary energy current at full load. The loss in the motor under these conditions may be assumed to be equal to the load losses $+I^2\,r$ losses in both primary and secondary coils.

(*G*) UNIPOLAR OR ACYCLIC MACHINES.

168 In UNIPOLAR MACHINES, the losses are:

169 (*a*) BEARING FRICTION AND WINDAGE. See Measurement of Losses (*A*), Sec. 102.

170 (*b*) MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS. See Measurement of Losses (*E*), Sec. 106.

171 (*c*) ARMATURE-RESISTANCE LOSSES. See Measurement of Losses (*E*), Sec. 110.

172 (*d*) COLLECTOR-BRUSH FRICTION. See Measurement of Losses (*C*), Sec. 104.

Digitized by Google

173 (*e*) COLLECTOR BRUSH-CONTACT RESISTANCE. See Measurement of Losses (*G*), Sec. 112.

174 (*f*) FIELD-EXCITATION. See Measurement of Losses (*H*), Sec. 113.

175 (*g*) LOAD LOSSES. See Measurement of Losses (*I*), Sec. 114.

(*H*) RECTIFYING APPARATUS, PULSATING-CURRENT GENERATORS.

176 This division includes: open-coil arc machines and mechanical and other rectifiers.

177 In RECTIFIERS the most satisfactory method of determining the efficiency is to measure both electric input and electric output by wattmeter. The input is usually inductive, owing to phase displacement and to wave distortion. For this reason the power factor and the apparent efficiency should also be considered, since the latter may be much lower than the true efficiency. The power consumed by auxiliary devices, such as the synchronous motor or cooling devices, should be included in the electric input.

178 In CONSTANT-CURRENT RECTIFIERS, transforming from constant potential alternating to constant direct current, by means of constant-current transforming devices and rectifying devices, the losses in the transforming devices are to be included in determining the efficiency and have to be measured when operating the rectifier, since in this case the losses may be greater than when feeding an alternating secondary circuit. In constant-current transforming devices, the load losses may be considerable, and therefore, should not be neglected.

179 In OPEN-COIL ARC MACHINES, the losses are essentially the same as in direct-current (closed coil) commutating machines. In this case, however, the load losses are usually greater, and the efficiency should preferably be measured by input- and output-test, using wattmeters for measuring the output.

179a In alternating-current rectifiers, the output should, in general, be measured by wattmeter and not by voltmeter and ammeter, since owing to pulsation of current and voltage, a considerable discrepancy may exist between watts and volt-amperes. If, however, a direct-current and an alternating-current meter in the rectified circuit (either a voltmeter or an ammeter) give the same reading, the output may be measured by direct-current voltmeter and ammeter. The type of alternating-current instrument here referred to should indicate the effective or root-of-mean-square value and the type of direct-current instrument the arithmetical mean value, which would be zero on an alternating-current circuit.

(*I*) TRANSMISSION LINES.

180 The EFFICIENCY of transmission lines should be measured with non-inductive load at the receiving end, with the rated receiving voltage and frequency, also with sinusoidal impressed wave form, except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the ends of the line.

(*J*) PHASE-DISPLACING APPARATUS.

183 In SYNCHRONOUS PHASE-MODIFIERS and exciters of induction generators, the determination of losses is the same as in other synchronous machines.

184 In REACTORS the losses are molecular magnetic friction, eddy losses and $I^2 r$ loss. They should be measured by wattmeter. The losses of reactors should be determined with a sine wave of impressed voltage except where expressly specified otherwise.

185 In CONDENSERS, the losses are due to dielectric hysteresis and leakage, and should be determined by wattmeter with a sine wave of voltage or by an alternating-current bridge method.

186 In POLARIZATION CELLS, the losses are those due to electric resistivity and a loss in the electrolyte of the nature of chemical hysteresis. These losses may be considerable. They depend upon the frequency, voltage and temperature, and should be determined with a sine wave of impressed voltage, except where expressly specified otherwise.

Digitized by Google

D. REGULATION.

(I) *DEFINITIONS.*

187 The REGULATION of a machine or apparatus in regard to some characteristic quantity (such as terminal voltage, current or speed) is the ratio of the deviation of that quantity from its normal value at rated load to that normal value. The term "regulation," therefore, has the same meaning as the term "inherent regulation," occasionally used.

188 CONSTANT STANDARD. If the characteristic quantity is intended to remain constant (*e.g.*, constant voltage, constant speed, etc.) between rated load and no load, the regulation is the ratio of the maximum variation from the rated-load value to the no-load value.

189 VARYING STANDARD. If the characteristic quantity is intended to vary in a definite manner between rated load and no load, the regulation is the ratio of the maximum variation from the specified condition to the normal rated-load value.

190 (*a*) NOTE. If the law of the variation (in voltage, current, speed, etc.) between rated load and no load is not specified, it should be assumed to be a simple linear relation; *i.e.*, one undergoing uniform variation between rated load and no load.

191 (*b*) NOTE. The regulation of an apparatus may, therefore differ according to its qualification for use. Thus, the regulation of a compound-wound generator specified as a constant-potential generator, will be different from that which it possesses when specified as an over-compounded generator.

192 In CONSTANT-POTENTIAL MACHINES, the regulation is the ratio of the maximum difference of terminal voltage from the rated-load value (occurring within the range from rated load to open circuit) to the rated load terminal voltage.

193 In CONSTANT-CURRENT MACHINES, the regulation is the ratio of the maximum difference of current from the rated-load value (occurring within the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

194 In CONSTANT-POWER APPARATUS, the regulation is the ratio of maximum difference of power from the rated load value (occurring within the range of operation specified) to the rated power.

195 In CONSTANT-SPEED DIRECT-CURRENT MOTORS and INDUCTION MOTORS the regulation is the ratio of the maximum variation of speed from its rated load value (occurring within the range from rated load to no-load) to the rated load speed.

196 The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism, to the synchronous speed.

197 In CONSTANT-POTENTIAL TRANSFORMERS, the regulation is the ratio of the rise of secondary terminal voltage from rated non-inductive load to no-load (at constant primary impressed terminal voltage) to the secondary terminal voltage at rated load.

198 In OVER-COMPOUNDED MACHINES, the regulation is the ratio of the maximum difference in voltage from a straight line connecting the no-load and rated-load values of terminal voltage as function of the load current, to the rated-load terminal voltage.

199 In CONVERTERS, DYNAMOTORS, MOTOR-GENERATORS AND FREQUENCY CONVERTERS, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated-load voltage, to the rated-load voltage on the output side.

200 In TRANSMISSION LINES, FEEDERS, ETC., the regulation is the ratio of the maximum voltage difference at the receiving end, between rated non-inductive load and no load to the rated-load voltage at the receiving end (with constant voltage impressed upon the sending end).

201 In STEAM ENGINES, the regulation is the ratio of the maximum variation of speed in passing slowly from rated-load to no-load (with constant steam pressure at the throttle) to the rated-load speed. For variation and pulsation see Secs. 59–64.

Digitized by Google

202 In a HYDRAULIC TURBINE or OTHER WATER-MOTOR, the regulation is the ratio of the maximum variation of speed in passing slowly from rated-load to no-load (at constant head of water; *i.e.*, at constant difference of level between tail race and head race), to the rated-load speed. For variation and pulsation see Secs. 59–64.

203 In a GENERATOR-UNIT, consisting of a generator united with a prime-mover, the regulation should be determined at constant conditions of the prime-mover; *i.e.*, constant steam pressure, head, etc. It includes the inherent speed variations of the prime-mover. For this reason the regulation of a generator-unit is to be distinguished from the regulation of either the prime-mover, or of the generator contained in it, when taken separately.

(II) *CONDITIONS FOR AND TESTS OF REGULATION.*

204 SPEED. The REGULATION OF GENERATORS is to be determined at constant speed, and of alternating apparatus at constant impressed frequency.

205 NON-INDUCTIVE LOAD. In apparatus generating, transforming or transmitting alternating currents, regulation should be understood to refer to non-inductive load, that is, to a load in which the current is in phase with the e.m.f. at the output side of the apparatus, except where expressly specified otherwise.

206 WAVE FORM. In alternating apparatus receiving electric power, regulation should refer to a sine wave of e.m.f., except where expressly specified otherwise.

207 EXCITATION. In commutating machines, rectifying machines, and synchronous machines, such as direct-current generators and motors, alternating-current and polyphase generators, the regulation is to be determined under the following conditions:

(1) At constant excitation in separately excited fields.

(2) With constant resistance in shunt-field circuits, and

(3) With constant resistance shunting series-field circuits; *i.e.*, the field adjustment should remain constant, and should be so chosen as to give the required rated-load voltage at rated-load current.

208 IMPEDANCE RATIO. In alternating-current apparatus, in addition to the non-inductive regulation, the impedance ratio of the apparatus should be specified; *i.e.*, the ratio of the voltage consumed by the total internal impedance of the apparatus at rated-load current, to its rated-load voltage. As far as possible, a sinusoidal current should be used.

209 COMPUTATION OF REGULATION. In synchronous machines the open-circuit exciting ampere-turns corresponding to terminal voltage plus armature-resistance-drop, and the exciting ampere-turns at short-circuit for rated-load current should be combined vectorially to obtain the resultant ampere-turns, and the corresponding internal e.m.f. should be taken from the saturation curve.

E. INSULATION.

(I) *INSULATION RESISTANCE.*

210 INSULATION RESISTANCE is the ohmic resistance offered by an insulating coating, cover, material or support to an impressed voltage, tending to produce a leakage of current through the same.

211 OHMIC RESISTANCE AND DIELECTRIC STRENGTH. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage. Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

212 RECOMMENDED VALUE OF RESISTANCE. The insulation resistance of completed apparatus should be such that the rated terminal voltage of the apparatus will not send more than $\frac{1}{1,000,000}$ of the rated-load current,

Digitized by Google

through the insulation. Where the value found in this way exceeds one megohm, it is usually sufficient.

213 INSULATION RESISTANCE TESTS should, if possible, be made at the pressure for which the apparatus is designed.

(II) *DIELECTRIC STRENGTH.*

(*A*) TEST VOLTAGES.

214 DEFINITION. The dielectric strength of an insulating wall, coating, cover or path is measured by the voltage which must be applied to it in order to effect a disruptive discharge through the same.

215 BASIS FOR DETERMINING TEST VOLTAGES. The test voltage which should be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the apparatus and its normal operating voltage, upon the nature of the service in which it is to be used, and the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended have been determined as reasonable and proper for the great majority of cases and are proposed for general adoption, except when specific reasons make a modification desirable.

216 CONDITION OF APPARATUS TO BE TESTED. Commercial tests should, in general, be made with the completely assembled apparatus and not with individual parts. The apparatus should be in good condition and high-voltage tests, unless otherwise specified, should be applied before the machine is put into commercial service, and should not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests should, in general, be made at the temperature assumed under normal operation. High-voltage tests considerably in excess of the normal voltages to determine whether specifications are fulfilled are admissable on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine should be understood as being made at the factory.

217 POINTS OF APPLICATION OF VOLTAGE. The test voltage should be successively applied between each electric circuit and all other electric circuits including conducting material in the apparatus.

218 The FREQUENCY of the alternating-current test voltage is, in general, immaterial within commercial ranges. When, however, the frequency has an appreciable effect, as in alternating-current apparatus of high voltage and considerable capacity, the rated frequency of the apparatus should be used.

219 TABLE OF TESTING VOLTAGES. The following voltages are recommended for testing all apparatus, lines and cables, by a continued application for one minute. The test should be with alternating voltage having a virtual value (or root mean square referred to a sine wave of voltage) given in the table, and preferably for tests of alternating apparatus at the normal frequency of the apparatus.

220

Rated Terminal Voltage of Circuit.	Rated Output.	Testing Voltage.
Not exceeding 400 volts	Under 10 kw	1,000 volts.
" " "	10 kw. and over	1,500 "
400 and over, but less than 800 volts	Under 10 kw	1,500 "
" " " " "	10 kw. and over	2,000 "
800 " " 1,200 "	Any	3,500 "
1,200 " " 2,500 "	Any	5,000 "
2,500 " "	Any	Double the normal rated voltages.

221 EXCEPTION.—TRANSFORMERS. Transformers having primary pressures of from 550 to 5,000 volts, the secondaries of which are directly connected to consumption circuits, should have a testing voltage of 10,000 volts, to be applied between the primary and secondary windings, and also between the primary winding and the core.

222 EXCEPTION.—FIELD WINDINGS. The tests for field windings should be based on the rated voltage of the exciter and the rated output of the machine of which the coils are a part. Field windings of synchronous motors and converters, which are to be started by applying alternating current to the armature when the field is not excited and when a high voltage is induced in the field windings, should be tested at 5,000 volts.

Digitized by Google

223 RATED TERMINAL VOLTAGE.—DEFINITION. The rated terminal voltage of circuit in the above table, means the voltage between the conductors of the circuit to which the apparatus to be tested is to be connected,—for instance, in three-phase circuits the delta voltage should be taken. In the following specific cases, the rated terminal voltage of the circuit is to be determined as specified in ascertaining the testing voltage:

224 (*a*) TRANSFORMERS. The test of the insulation between the primary and secondary windings of transformers is to be the same as that between the high-voltage windings and core, and both tests should be made simultaneously by connecting the low-voltage winding and core together during the test. If a voltage equal to the specified testing voltage be induced in the high-voltage winding of a transformer it may be used for insulation tests instead of an independently induced voltage. These tests should be made first with one end and then with the other end of the high-tension winding connected to the low-tension winding and to the core.

225 (*b*) CONSTANT-CURRENT APPARATUS. The testing voltage is to be based upon a rated terminal voltage equal to the maximum voltage which may exist at open or closed circuit.

226 (*c*) APPARATUS IN SERIES. For tests of machines or apparatus to be operated in series, so as to employ the sum of their separate voltages the testing voltage is to be based upon a rated terminal voltage equal to the sum of the separate voltages except where the frames of the machines are separately insulated, both from the ground and from each other, in which case the test for insulation between machines should be based upon the voltage of one machine, and the test between each machine and ground to be based upon the total voltage of the series.

(*B*) METHODS OF TESTING.

227 CLASSES OF TESTS. Tests for dielectric strength cover such a wide range in voltage that the apparatus, methods and precautions which are essential in certain cases do not apply to others. For convenience, the tests will be separated into two classes:

228 CLASS 1. This class includes all apparatus for which the test voltage does not exceed 10 kilovolts, unless the apparatus is of very large static capacity, *e.g.*, a large cable system. This class also includes all apparatus of small static capacity, such as line insulators, switches and the like, for all test voltages.

229 METHOD OF TEST FOR CLASS 1. The test voltage is to be continuously applied for the prescribed interval,—(one minute unless otherwise specified). The test voltage may be taken from a constant-potential source and applied directly to the apparatus to be tested, or it may be raised gradually as specified for tests under Class 2.

230 CLASS 2. This class includes all apparatus not included in Class 1.

231 METHOD OF TEST FOR CLASS 2. The test voltage is to be raised to the required value smoothly and without sudden large increments and is then to be continuously applied for the prescribed interval,—(one minute, unless otherwise specified), and then gradually decreased.

232 CONDITIONS AND PRECAUTIONS FOR CLASS 1 and CLASS 2. The following apply to all tests:

233 The WAVE SHAPE should be approximately sinusoidal and the apparatus in the testing circuits should not materially distort this wave.

234 The SUPPLY CIRCUIT should have ample current-supply capacity so that the charging current which may be taken by the apparatus under test will not materially alter the wave form nor materially affect the test voltage. The circuit should be free from accidental interruptions.

235 RESISTANCE OR INDUCTANCE in series with the primary of a raising transformer for the purpose of controlling its voltage is liable seriously to affect the wave form, thereby causing the maximum value of the voltage to bear a different and unknown ratio to the root mean square value. This method of voltage adjustment is, therefore, in general, undesirable. It may be noted that if a resistance or inductance is employed to limit the current when burning out a fault, such resistance or inductance should be short circuited during the regular voltage test.

Digitized by Google

236 The INSULATION under test should be in normal condition as to dryness and the temperature should when possible be that reached in normal service.

237 ADDITIONAL CONDITIONS AND PRECAUTIONS FOR CLASS 2. The following conditions and precautions, in addition to the foregoing, apply to tests of apparatus included in Class 2.

238 SUDDEN INCREMENT OF TESTING VOLTAGE on the apparatus under test should be avoided, particularly at high voltages and with apparatus having considerable capacity, as a momentarily excessive rise in testing voltage will result.

239 SUDDEN VARIATIONS IN TESTING VOLTAGE of the circuit supplying the voltage during the test should be avoided as they are likely to set up injurious oscillation.

240 GOOD CONNECTIONS in the circuits supplying the test voltage are essential in order to prevent injurious high frequency disturbances from being set up. When a heavy current is carried by a small water rheostat, arcing may occur, causing high-frequency disturbances which should be carefully avoided.

241 TRANSFORMER COILS. In high-voltage transformers, the low-voltage coil should preferably be connected to the core and to the ground when the high-voltage test is being made, in order to avoid the stress from low-voltage coil to core, which would otherwise result through condenser action. The various terminals of each winding of the high-tension transformer under test should be connected together during the test in order to prevent undue stress on the insulation between turns or sections of the winding in case the high-voltage test causes a break-down.

(*C*) METHODS FOR MEASURING THE TEST VOLTAGE.

242 FOR MEASURING THE TEST VOLTAGE, two instruments are in common use, (1) the spark gap and (2) the voltmeter.

243 1. THE SPARK GAP is ordinarily adjusted so that it will break down with a certain predetermined voltage, and is connected in parallel with the insulation under test. It ensures that the voltage applied to the insulation is not greater than the break-down voltage of the spark gap. A given setting of the spark gap is a measure of one definite voltage, and, as its operation depends upon the maximum value of the voltage wave, it is independent of wave form and is a limit on the maximum stress to which the insulation is subjected. The spark gap is not conveniently adapted for comparatively low voltages.

244 In SPARK-GAP MEASUREMENTS, the spark gap may be set for the required voltage and the auxiliary apparatus adjusted to give a voltage at which this spark gap just breaks down. The spark gap should then be adjusted for, say, 10 per cent higher voltage, and the auxiliary apparatus again adjusted to give the voltage of the former breakdown, which is to be the assumed voltage for the test. This voltage is to be maintained for the required interval.

245 The SPARK POINTS should consist of new sewing needles, supported axially at the ends of linear conductors which are each at least twice the length of the gap. There should be no extraneous body near the gap within a radius of twice its length. A table of approximate striking distances is given in Appendix D. This table should be used in connection with tests made by the spark-gap methods.

246 A NON-INDUCTIVE RESISTANCE of about one-half ohm per volt should be inserted in series with each terminal of the gap so as to keep the discharge current between the limits of one-quarter ampere and 2 amperes. The purpose of the resistance is to limit the current in order to prevent the surges which might otherwise occur at the time of break-down.

247 2. The VOLTMETER gives a direct reading, and the different values of the voltage can be read during the application and duration of the test. It is suitable for all voltages, and does not introduce disturbances into the test circuit.

248 In VOLTMETER MEASUREMENTS, the voltmeter should, in general, derive its voltage from the high-tension testing circuit either directly or through

Digitized by Google

an auxiliary ratio transformer. It is permissible, however, to measure the voltage at other places,—for example, on the primary of the transformer, provided the ratio of transformation does not materially vary during the test; or that proper account is taken thereof.

249 SPARK GAP AND VOLTMETER. The spark gap may be employed as a check upon the voltmeter used in high-tension tests in order to determine the transformation ratio of the transformer, the variation from the sine wave form and the like. It is also useful in conjunction with voltmeter measurements to limit the stress applied to the insulating material.

(*D*) APPARATUS FOR SUPPLYING TEST VOLTAGE.

250 The GENERATOR OR CIRCUIT supplying voltage for the test should have ample current carrying capacity, so that the current which may be taken for charging the apparatus to be tested will not materially alter the wave form nor otherwise materially change the voltage.

The TESTING TRANSFORMER should be such that its ratio of transformation does not vary more than 10 per cent when delivering the charging current required by the apparatus under test. (This may be determined by short-circuiting the secondary or high voltage winding of the testing transformer and supplying 1/10 of the primary voltage to the primary under this condition. The primary current that flows under this condition is the maximum which should be permitted in regular dielectric test.)

251 The VOLTAGE CONTROL may be secured in either of several ways, which in order of preference, are as follows:

252 1. By generator field circuit.

253 2. By magnetic commutation.

254 3. By change in transformer ratio.

255 4. By resistance or choke coils.

256 In GENERATOR VOLTAGE CONTROL, the voltage of the generator should preferably be about its approximate normal rated load value when the full testing voltage is attained, which requires that the ratio of the raising transformer be such that the full testing voltage is reached when the generator voltage is normal. This avoids the instability in the generator which may occur if a considerable leading current is taken from it when it has low voltage and low field current.

257 In MAGNETIC COMMUTATION, the control is effected by shunting the magmetic flux through a secondary coil so as to vary the induction through the coil and the voltage induced in it. The shunting should be effected smoothly, thus avoiding sudden changes in the induced voltage.

258 In TRANSFORMER VOLTAGE CONTROL, by change of ratio, it is necessary that the transition from one step to another be made without interruption of the test voltage, and by steps sufficiently small to prevent surges in the testing circuit. The necessity of this precaution is greater as the inductance or the static capacity of the apparatus in the testing circuit under test is greater.

259 When RESISTANCE COILS OR REACTORS are used for voltage control, it is desirable that the testing voltage should be secured when the controlling resistance or reactance is very nearly or entirely out of circuit in order that the disturbing effect upon the wave form which results may be negligible at the highest voltage.

F. CONDUCTIVITY.

260 COPPER. The conductivity of copper in annealed wires and in electric cables should not be less than 98 per cent of the Annealed Copper Standard, and the conductivity of hard-drawn copper wires should not be less than 95 per cent of the Annealed Copper Standard. The Annealed Copper Standard represents a mass-resistivity of 0.153022 ohm per meter-gram at 20 deg. cent. or 873.75 ohms per mile-pound at 20 deg. cent.; or using a density of 8.89, a volume-resistivity of 1.72128 microhm-cm., or microhms in a cm. cube, at 20 deg. cent. or 0.67767microhm-inch at 20 deg. cent.

Digitized by Google

G. RISE OF TEMPERATURE.

(I) *MEASUREMENT OF TEMPERATURE.*

(*A*) METHODS.

261 There are two methods in common use for determining the rise in temperature, *viz.*: (1) by thermometer, and (2) by increase in resistance of an electric circuit.

262 1. By THERMOMETER. The following precautions should be observed in the use of thermometers:

263 *a.* PROTECTION. The thermometers indicating the room temperature should be protected from thermal radiation emitted by heated bodies, or from draughts of air or from temporary fluctuations of temperature. Several room thermometers should be used. In using the thermometer by applying it to a heated part, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

264 *b.* BULB. When a thermometer is applied to the free surface of a machine, it is desirable that the bulb of the thermometer should be covered by a pad of definite area. A convenient pad may be formed of cotton waste in a shallow circular box about one and a half inches in diameter, through a slot in the side in which the thermometer bulb is inserted. An unduly large pad over the thermometer tends to interfere with the natural liberation of heat from the surface to which the thermometer is applied.

265 2. By INCREASE IN RESISTANCE. The resistance may be measured either by the Wheatstone bridge, the Thomson or Kelvin double bridge, the potentiometer method, or the ammeter and voltmeter method. If a temperature coefficient must be assumed, its value for copper may be taken to be 0.00394 per deg. cent. from and at 20 deg. cent., or 0.00428 per deg. cent. from and at 0 deg. cent. This value holds for average commercial *annealed* copper. If the copper wire is hard-drawn, or if the conductivity is known, a different value of temperature coefficient should be taken, according to the explanation and discussion of the temperature coefficient in Appendix E.

The temperature rise may be determined either (1) by dividing the per cent increase of initial resistance by the temperature coefficient for the initial temperature expressed in per cent; or (2) by multiplying the increase in per cent of the initial resistance by T plus the initial temperature in degrees cent., and then dividing the product by 100. ($-T$ is the "inferred absolute zero temperature of resistance" and is given in the last column of the table in Appendix E. For average commercial *annealed* copper it is 233.8).

266 3. COMPARISON OF METHODS. In electrical conductors, the rise of temperature should be determined by their increase of resistance where practicable. Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers. In very low resistance circuits, thermometer measurements are frequently more reliable than measurements by the resistance method. Where a thermometer applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted.

(*B*) NORMAL CONDITIONS FOR TESTS.

267 1. DURATION OF TESTS. The temperature should be measured after a run of sufficient duration for the apparatus to reach a practically constant temperature. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

268 2. ROOM TEMPERATURE. The rise of temperature should be referred to the standard condition of a room temperature of 25 deg. cent.

269 TEMPERATURE CORRECTION. If the room temperature during the test

Digitized by Google

differs from 25 deg. cent., correction on account of difference in resistance should be made by changing the observed rise of temperature by one-half per cent for each degree centigrade. Thus with a room temperature of 35 deg. cent., the observed rise of temperature has to be decreased by 5 per cent, and with a room temperature of 15 deg. cent., the observed rise of temperature has to be increased by 5 per cent. In certain cases, such as shunt-field circuits without rheostat, the current strength will be changed by a change of room temperature. The heat-production and dissipation may be thereby affected. Correction for this should be made by changing the observed rise in temperature in proportion as the $I^2 R$ loss in the resistance of the apparatus is altered owing to the difference in room temperature.

270 3. BAROMETRIC PRESSURE. VENTILATION. A barometric pressure of 760 mm. and normal conditions of ventilation should be considered as standard, and the apparatus under test should neither be exposed to draught nor enclosed, except where expressly specified. The barometric pressure needs to be considered only when differing greatly from 760 mm.

271 BAROMETRIC PRESSURE CORRECTION. When the barometric pressure differs greatly from the standard pressure of 760 mm. of mercury, as at high altitudes, a correction should be applied. In the absence of more nearly accurate data, a correction of one per cent of the observed rise in temperature for each 10 mm. deviation from the 760-mm. standard is recommended. For example at a barometric pressure of 680 mm. the observed rise of temperature is to be reduced by $\frac{760-680}{10} = 8$ per cent.

(II) *LIMITING TEMPERATURE RISE.*

272 GENERAL. The temperature of electrical machinery under regular service conditions, should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

273 LIMITS RECOMMENDED. It is recommended that the following maximum values of temperature elevation, referred to a standard room temperature of 25 degrees centigrade, at rated load under normal conditions of ventilation or cooling, should not be exceeded.

(*A*) MACHINES IN GENERAL.

274 In commutating machines, rectifying machines, pulsating-current generators, synchronous machines, synchronous commutating machines and unipolar machines, the temperature rise in the parts specified should not exceed the following:

275 Field and armature, 50 deg. cent.

276 Commutator and brushes, by thermometer, 55 deg. cent.

277 Collector rings, 65 deg. cent.

278 Bearings and other parts of machine, by thermometer, 40 deg. cent.

279 (*B*) ROTARY INDUCTION APPARATUS. The temperature rise should not exceed the following:

280 Electric circuits, 50 deg. cent., by resistance.

281 Bearings and other parts of the machine 40 deg. cent., by thermometer.

282 In squirrel-cage or short-circuited armatures, 55 deg. cent., by thermometer, may be allowed.

(*C*) STATIONARY INDUCTION APPARATUS.

283 *a.* TRANSFORMERS FOR CONTINUOUS SERVICE. The temperature rise should not exceed 50 deg. cent. in electric circuits, by resistance; and in other parts, by thermometer.

284 *b.* TRANSFORMERS FOR INTERMITTENT SERVICE. In the case of transformers intended for intermittent service, or not operating continuously at rated load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air-temperature should not exceed 50 deg. cent., by resistance in electric circuits and by thermometer in other parts, after the period corresponding to the term of rated load. In this instance, the test load should not be applied

Digitized by Google

until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the rated-load test may be taken as three hours, unless otherwise specified.

285 *c.* REACTORS, INDUCTION- AND MAGNETO-REGULATORS. Electric circuits by resistance and other parts by thermometer, 50 deg. cent.

286 *d.* LARGE APPARATUS. Large generators, motors, transformers, or other apparatus in which reliability and reserve overload capacity are important, are frequently specified not to rise in temperature more than 40 deg. cent. under rated load and 55 deg. cent. at rated overload. It is, however, ordinarily undesirable to specify lower temperature elevations than 40 deg. cent. at rated load, measured as above.

(*D*) RHEOSTATS.

287 In RHEOSTATS, HEATERS and other electrothermal apparatus, no combustible or inflammable part or material, or portion liable to come in contact with such material, should rise more than 50 deg. cent. above the surrounding air under the service conditions for which it is designed.

288 *a.* PARTS OF RHEOSTATS. Parts of rheostats and similar apparatus rising in temperature, under the specified service conditions, more than 50 deg. cent., should not contain any combustible material, and should be arranged or installed in such a manner that neither they, nor the hot air issuing from them, can come in contact with combustible material.

(*E*) LIMITS RECOMMENDED IN SPECIAL CASES.

289 *a.* HEAT RESISTING INSULATION. With apparatus in which the insulating materials have special heat-resisting qualities, a higher temperature elevation is permissible.

290 *b.* HIGH AIR TEMPERATURE. In apparatus intended for service in places of abnormally high temperature, a lower temperature elevation should be specified.

291 *c.* APPARATUS SUBJECT TO OVERLOAD. In apparatus which by the nature of its service may be exposed to overload, or is to be used in very high voltage circuits, a smaller rise of temperature is desirable than in apparatus not liable to overloads or in low-voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

292 *d.* APPARATUS FOR INTERMITTENT SERVICE. In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of rated load, should not exceed the values specified for machines in general. In such apparatus, including railway motors, the temperature elevation should be measured after operation, under as nearly as possible the conditions of service for which the apparatus is intended, and the conditions of the test should be specified.

H. OVERLOAD CAPACITIES.

293 PERFORMANCE WITH OVERLOAD. All apparatus should be able to carry the overload hereinafter specified without serious injury by heating, sparking, mechanical weakness, etc., and with an additional temperature rise not exceeding 15 deg. cent., above those specified for rated loads, the overload being applied after the apparatus has acquired the temperature corresponding to rated load continuous operation. Rheostats to which no temperature rise limits are attached are naturally exempt from this additional temperature rise of 15 deg. cent. under overload specified in these rules.

294 NORMAL CONDITIONS. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

Digitized by Google

295 OVERLOAD CAPACITIES RECOMMENDED. The following overload capacities are recommended:

296 *a.* GENERATORS. Direct-current generators and alternating-current generators, 25 per cent for two hours.

297 *b.* MOTORS. Direct-current motors, induction motors and synchronous motors, not including railway and other motors intended for intermittent service, 25 per cent for two hours, and 50 per cent for one minute.

298 *c.* CONVERTERS. Synchronous converters, 25 per cent for two hours, 50 per cent for one-half hour.

299 *d.* TRANSFORMERS AND RECTIFIERS. Constant-potential transformers and rectifiers, 25 per cent for two hours; except in transformers connected to apparatus for which a different overload is guaranteed in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

300 *e.* EXCITERS. Exciters of alternators and other synchronous machines, 10 per cent more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time. All exciters of alternating-current, single-phase or polyphase generators, should be able to give at their rated speed, sufficient voltage and current to excite their alternators, at the rated speed, to the full-load terminal voltage, at the rated output in kilovolt-amperes and with 50 per cent power factor.

301 *f.* A CONTINUOUS-SERVICE RHEOSTAT, such as an armature- or field-regulating rheostat, should be capable of carrying without injury for two hours, a current 25 per cent greater than that at which it is rated. It should also be capable of carrying for one minute a current 50 per cent greater than its rated load current, without injury. This excess of capacity is intended for testing purposes only, and this margin of capacity should not be relied upon in the selection of the rheostat.

302 *g.* An INTERMITTENT SERVICE OR MOTOR-STARTING RHEOSTAT is used for starting a motor from rest and accelerating it to rated speed. Under ordinary conditions of service, and unless expressly stated otherwise, a motor is assumed to start in fifteen seconds and with 150 per cent of rated current strength. A motor-starter should be capable of starting the motor under these conditions once every four minutes for one hour.

303 (*a*) This TEST may be carried out either by starting the motor at four-minute intervals, or by placing the starter at normal temperature across the maximum voltage for which it is marked, and moving the lever uniformly and gradually from the first to the last position during a period of fifteen seconds, the current being maintained substantially constant at said 50 per cent excess, by introducing resistance in series or by other suitable means.

304 (*b*) OTHER RHEOSTATS FOR INTERMITTENT-SERVICE are employed under such special and varied conditions, that no general rules are applicable to them.

III. VOLTAGES AND FREQUENCIES.

A. VOLTAGES.

305 DIRECT-CURRENT GENERATORS. In direct-current, low-voltage generators, the following average terminal voltages are in general use and are recommended:

125 volts. 250 volts. 600 volts.

306 LOW-VOLTAGE CIRCUITS. In direct-current low-voltage circuits, the following terminal voltages are in general use and are recommended:

115 volts. 230 volts. 550 volts.

In alternating-current low-voltage circuits, the following terminal voltages are in general use and are recommended.

110 volts. 220 volts. 440 volts. 550 volts.

Digitized by Google

307 PRIMARY DISTRIBUTION CIRCUITS. In alternating-current, constant-potential, primary-distribution circuits, an average voltage of 2,200 volts, with step-down transformer ratios 1/10 and 1/20, is in general use, and is recommended.

308 TRANSMISSION CIRCUITS. In alternating-current constant-potential transmission circuits, the following impressed voltages are recommended.

6,600 11,000 22,000 33,000 44,000 66,000 88,000 110,000

309 TRANSFORMER RATIO. It is recommended that the standard transformer ratios should be such as to transform between the standard voltages above named. The ratio will, therefore, usually be an exact multiple of 5 or 10, *e.g.*, 2,200 to 11,000; 2,200 to 44,000.

310 RANGE IN VOLTAGE. In alternating-current generators, or generating systems, a range of terminal voltage should be provided from rated voltage at no load to 10 per cent in excess thereof, to cover drop in transmission. If a greater range than ten per cent is specified, the generator should be considered as special.

B. FREQUENCIES.

311 In ALTERNATING-CURRENT CIRCUITS, the following frequencies are, standard:

25 cycles 60 cycles

312 These frequencies are already in extensive use and it is deemed advisable to adhere to them as closely as possible.

IV. GENERAL RECOMMENDATIONS.

313 NAME PLATES. All electrical apparatus should be provided with a name plate giving the manufacturers' name, the voltage and the current in amperes for which it is designed. Where practicable, the kilowatt capacity, character of current, speed, frequency, type, designation and serial number should be added.

314 DIAGRAMS OF CONNECTIONS. All electrical apparatus when leaving the factory should be accompanied by a diagram showing the electrical connections and the relation of the different parts in sufficient detail to give the necessary information for proper installation.

315 RHEOSTAT DATA. Every rheostat should be clearly and permanently marked with the voltage and amperes, or range of amperes, for which it is designed.

316 COLORED INDICATING LIGHTS. When using colored indicating lights on switch-boards, red should denote danger such as "switch closed," or "circuit alive"; green should denote safety, such as "switch open," or "circuit dead."

317 When white lights are used a light turned on should denote danger, such as "switch closed" or "circuit alive"; while the light out should denote safety, such as "switch open," or "circuit dead." Low-efficiency lamps should be used on account of their lesser liability to accidental burn-out.

318 The use of colored lights is recommended, as safer than white lights.

319 GROUNDING METAL WORK. It is desirable that all metal work near high potential circuits be grounded.

320 CIRCUIT OPENING DEVICES. The following definitions are recommended.

321 *a.* A CIRCUIT-BREAKER is an apparatus for breaking a circuit at the highest current which it may be called upon to carry.

322 *b.* A DISCONNECTING SWITCH is an apparatus designed to open a circuit only when carrying little or no current.

323 *c.* An AUTOMATIC CIRCUIT-BREAKER is an apparatus for breaking a circuit automatically under an excessive strength of current. It should be capable of breaking the circuit repeatedly at rated voltage and at the maximum current which it may be called upon to carry.

Digitized by Google

V. APPENDICES AND TABULAR DATA.

APPENDIX A. NOTATION.

The following notation is recommended:

	Name of Quantity	Symbol	Unit
324	Voltage, e.m.f., potential difference	E, e,	volt
	Current	I, i,	ampere
	Resistance	R, r,	ohm
	Reactance	X, x,	"
	Impedance	Z, z,	"
	Admittance	Y, y,	mho
	Conductance	G, g,	"
	Susceptance	B, b,	"
	Power	P, p,	watt
	Capacity	C, c,	farad
	Inductance	$\mathfrak{L}$, L,	henry
	Magnetic flux	Φ	maxwell
	Magnetic density	$\mathfrak{B}$,	gauss
	Magnetic force	H,	gilbert per cm.
	Length	L, l,	cm. or inch
	Mass	M, m,	gm. or lb.
	Time	T, t,	second or hour

E_m, I_m and B_m should preferably be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see Sec. 5g.) and P for the average value or effective power. These distinctions are not necessary in dealing with continuous-current circuits. Vector quantities are preferably represented by bold face capitals.

APPENDIX B.—RAILWAY MOTORS.

(I) *RATING.*

325 INTRODUCTORY NOTE ON RATING. Railway motors usually operate in a service in which both the speed and the torque developed by the motor are varying almost continually. The average requirements, however, during successive hours in a given class of service are fairly uniform. On account of the wide variation of the instantaneous loads, it is impracticable to assign any simple and definite rating to a motor which will indicate accurately the absolute capacity of a given motor or the relative capacity of different motors under service conditions. It is also impracticable to select a motor for a particular service without much fuller data with regard both to the motor and to the service than is required, for example, in the case of stationary motors which run at constant speeds.

326 SCOPE OF NOMINAL RATING. It is common usage to give railway motors a nominal rating in horse power on the basis of a one-hour test. As above explained, a simple rating of this kind is not a proper measure of service capacity. This nominal rating, however, indicates approximately the maximum output which the motor should ordinarily be called upon to develop during acceleration. Methods of determining the continuous capacity of a railway motor for service requirements are given under a subsequent heading.

327 The NOMINAL RATING of a railway motor is the horse-power output at the car-axle, that is, including gear and other transmission losses, which gives a rise of temperature above the surrounding air (referred to a room temperature of 25 deg. cent.) not exceeding 90 deg. cent. at the commutator and 75 deg. cent. at any other part after one hour's continuous run at its rated voltage (and frequency, in the case of an alternating-current motor) on a stand, with the motor-covers removed, and with natural ventilation. The rise in temperature is to be determined by thermometer, but the resistance of no electrical circuit in the motor shall increase more than 40 per cent during the test.

Digitized by Google

(II) *SELECTION OF MOTOR FOR SPECIFIED SERVICE.*

323 GENERAL REQUIREMENTS. The suitability of a railway motor for a specified service depends upon the following considerations:

329 *a.* Mechanical ability to develop the requisite torque and speeds as given by its speed-torque curve.

330 *b.* Ability to commutate successfully the current demanded.

331 *c.* Ability to operate in service without occasioning a temperature rise in any part which will endanger the life of the insulation.

332 OPERATING CONDITIONS, TYPICAL RUN. The operating conditions which are important in the selection of a motor include the weight of load, the schedule speed, the distance between stops, the duration of stops, the rate of acceleration and of braking retardation, the grades and the curves, with these data at hand, the outputs which are required of the motor may be determined, provided the service requirements are within the limits of the speed-torque curve of the motor. These outputs may be expressed in the form of curves giving the instantaneous values of current and of voltage which must be applied to the motor. Such curves may be laid out for the entire line, but they are usually constructed only for a certain average or typical run, which is fairly representative of the conditions of service. To determine whether the motor has sufficient capacity to perform the service safely, further tests or investigations must be made.

333 CAPACITY TEST OF RAILWAY MOTOR IN SERVICE. The capacity of a railway motor to deliver the necessary output may be determined by measurement of its temperature after it has reached a maximum in service. If a running test cannot be made under the actual conditions of service, an equivalent test may be made in a typical run back and forth, under such conditions of schedule speed, length of run, rate of acceleration, etc., that the test cycle of motor losses and conditions of ventilation are essentially the same as would be obtained in the specified service.

334 METHODS OF COMPARING MOTOR CAPACITY WITH SERVICE REQUIREMENTS. Where it is not convenient to test motors under actual service conditions or in an equivalent typical run, recourse may be had to one of the two following methods of determining temperature rise now in general use:

335 1. METHOD BY LOSSES AND THERMAL CAPACITY CURVES. The heat developed in a railway motor is carried partly by conduction through the several parts and partly by convection through the air to the motor-frame whence it is distributed to the outside air. As the temperature of the several parts is thus dependent not only upon their own internal losses but also upon the temperature of neighboring parts, it becomes necessary to determine accurately the actual value and distribution of losses in a railway motor for a given service and reproduce them in an equivalent test-run. The results of a series of typical runs expressed in the form of thermal capacity curves will give the relation between degrees rise per watt loss in the armature and in the field for all ratios of losses between them met with in the commercial application of a given motor.

336 This method consists, therefore, in calculating the several internal motor losses in a specified service and determining the temperature rise with these losses from thermal capacity curves giving the degrees rise per watt loss as obtained in experimental track tests made under the same conditions of ventilation.

337 The following motor losses cause its heating and should be carefully determined for a given service: $I^2 R$ in the field; $I^2 R$ in the armature; $I^2 R$ in the brush contacts, core loss and brush friction.

338 The loss in the bearings (in the case of geared motors) also adds somewhat to the motor-heating, but owing to the variable nature of such losses they are generally neglected in making calculations.

339 2. METHOD BY CONTINUOUS CAPACITY OF MOTOR. The essential losses in the motor, as found in the typical run, are in most cases those in the

Digitized by Google

motor windings and in the core. The mean service conditions may be expressed in terms of the current which would produce the same losses in the motor windings and the voltage which, with that current, would produce the same core losses as the average in service. The continuous capacity of the motor is given in terms of the amperes which it will carry when run on a testing stand—with covers on or off, as specified—at different voltages, say, 40, 60, 80 and 100 per cent of the rated voltage—with a temperature rise not exceeding 90 deg. cent at the commutator and 75 deg. cent at any other part, provided the resistance of no electric circuit in the motor increases more than 40 per cent. A comparison of the equivalent service conditions with the continuous capacity of the motor will determine whether the service requirements are within the safe capacity of the motor.

340 This method affords a ready means of determining whether a specified service is within the capacity of a given motor and it is also a convenient approximate method for comparing the service capacities of different motors.

APPENDIX C. PHOTOMETRY AND LAMPS.

341 CANDLE-POWER. The luminous intensity of sources of light is expressed in candle-power. The unit of candle-power is the international candle maintained by the Bureau of Standards at Washington, D. C. The Hefner unit is 0.90 of the international candle.

342 LUMEN. The total flux of light from a source is equal to its mean spherical intensity multiplied by 4π. The unit of flux is called the lumen. A lumen is the $\frac{1}{4\pi}$th part of the total flux of light emitted by a source having a mean spherical intensity of one candle-power.

344 ILLUMINATION. The fundamental physical unit of illumination is the centimeter-candle, or lumen per square centimeter of incident surface. This is a very intense illumination. It is, therefore, convenient to express illumination practically in thousandths of the fundamental unit; *i.e.*, in millilumens per sq. cm. In English-speaking countries, the unit of illumination commonly employed is the foot-candle or lumen per square foot. A foot-candle is nearly the same illumination as a millilumen per sq. cm. and is actually the more intense in the ratio 1.0764; so that n foot-candles $= 1.0764 \times n$ millilumens per sq. cm. A meter candle or lumen per square meter, is called a "lux". A foot-candle is 10.764 lux, and a millilumen per sq. cm. is exactly 10 lux.

346 The EFFICIENCY OF ELECTRIC LAMPS is properly stated in terms of lumens per watt at lamp terminals. This use of the term efficiency is to be considered as special, and not to be confused with the generally accepted definition of efficiency in Sec. 84.

347 *a.* EFFICIENCY, AUXILIARY DEVICES. In illuminants requiring auxiliary power-consuming devices outside of the luminous body, such as steadying resistances in constant potential arc lamps, a distinction should be made between the net efficiency and the gross efficiency of the lamp. This distinction should always be stated. The gross efficiency should include the power consumed in the auxiliary resistance, etc. The net efficiency should, however, include the power consumed in the controlling mechanism of the lamp itself. Comparison between such sources of light should be made on the basis of gross efficiency, since the power consumed in the auxiliary device is essential to the operation.

348 A STANDARD CIRCUIT VOLTAGE of 110 volts, or a multiple thereof may be assumed, except where expressly stated otherwise.

349 WATTS PER CANDLE. The specific consumption of an electric lamp is its watt consumption per mean spherical candle-power. "Watts per candle" is the term used commercially in connection with incandescent lamps, and denotes, watts per mean horizontal candle-power.

Digitized by Google

350 PHOTOMETRIC TESTS in which the results are stated in candle-power should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made at shorter distances, as for example in the measurement of lamps with reflectors, the results should always be given as "apparent candle-power" at the distance employed, which distance should always be specifically stated.

351 BASIS FOR COMPARISON. Either the total flux of light in lumens, or the mean spherical candle-power, should always be used as the basis for comparing various luminous sources with each other, unless there is a clear understanding or statement to the contrary.

352 INCANDESCENT LAMPS, RATING. It is customary to rate incandescent lamps on the basis of their mean horizontal candle-power; but in comparing incandescent lamps in which the relative distribution of luminous intensity differs, the comparison should be based on their total flux of light measured in lumens, or on their mean spherical candle-power.

352a LIFE TESTS. Similar filaments may be assumed to operate at the same temperature only when their lumens per watt consumed are the same. Life tests are comparable only when conducted under similar conditions as to filament temperatures.

353 The SPHERICAL REDUCTION-FACTOR of a lamp

$$= \frac{\text{mean spherical candle-power}}{\text{mean horizontal candle-power}}$$

354 The TOTAL FLUX of light in lumens emitted by a lamp $= 4\pi \times$ mean horizontal candle-power $\times$ spherical reduction-factor.

355 The SPHERICAL REDUCTION-FACTOR should only be used when properly determined for the particular type and characteristics of each lamp. The spherical reduction-factor permits of substantially accurate comparisons being made between the total lumens, or mean spherical candle-powers of different types of incandescent lamps, and may be used in the absence of proper facilities for direct measurement of the total lumens, or mean spherical candle-power.

356 "READING DISTANCE." Where standard photometric measurements are impracticable, approximate measurements of illuminants such as street lamps may be made by comparing their "reading distances;" *i.e.*, by determining alternately the distances at which an ordinary size of reading print can just be read, by the same person or persons, when all other light is screened. The angle below the horizontal at which the measurement is made should be specified when it exceeds 15 degrees. Reading-distance methods usually involve the comparison of very faint illuminations and hence the results may be seriously affected by the Purkinje effect.

357 In COMPARING DIFFERENT LUMINOUS SOURCES not only should their candle-power be compared, but also their relative form, brightness, distribution of illumination and character of light.

357a The following symbols are recommended in connection with photometry:

Photometric magnitude	Symbol	Unit
Intensity of light.	I	International candle.
Luminous flux.	F	Lumen.
Illumination.	E	Lumen/cm.^{2}, foot-candle.
Specific radiation.	R	Foot-candle.
Brightness.	b	Candle/cm.^{2}
Quantity.	Q	Candle.
Lighting.	L	Lumen-second, lumen-hour.

APPENDIX D. SPARKING DISTANCES.

358 Table of Sparking Distances in Air between Opposed Sharp Needle-Points, for Various Root-Mean-Square Sinusoidal Voltages, in inches and in centimeters. The table applies to the conditions specified in Secs. 240–246.

Digitized by Google

359

Kilovolts R.M.S.	Distance. Inches	Cm.	Kilovolts R.M.S.	Distance. Inches	Cm.
5	0.225	0.57	140	13.95	35.4
10	0.47	1.19	150	15.0	38.1
15	0.725	1.84	160	16.05	40.7
20	1.0	2.54	170	17.10	43.4
25	1.3	3.3	180	18.15	46.1
30	1.625	4.1	190	19.20	48.8
35	2.0	5.1	200	20.25	51.4
40	2.45	6.2	210	21.30	54.1
45	2.95	7.5	220	22.35	56.8
50	3.55	9.0	230	23.40	59.4
60	4.65	11.8	240	24.45	62.1
70	5.85	14.9	250	25.50	64.7
80	7.1	18.0	260	26.50	67.3
90	8.35	21.2	270	27.50	69.8
100	9.6	24.4	280	28.50	72.4
110	10.75	27.3	290	29.50	74.9
120	11.85	30.1	300	30.50	77.4
130	12.90	32.8			

APPENDIX E. TEMPERATURE COEFFICIENT OF COPPER.

360 The fundamental relation between the rise of temperature and the increase of resistance of copper may be expressed thus:

$$R_t = R_{t_1}(1 + \alpha_{t_1}[t - t_1])$$

where R_t is the resistance at any temperature t deg. cent.; R_{t_1} is the resistance at any "initial temperature" (or "temperature of reference") t_1 deg. cent.; and α_{t_1} is the temperature coefficient from and at the initial temperature t_1 deg. cent. Obviously the temperature coefficient is different for different initial temperatures, and this variation is shown in the horizontal rows of the table below. Furthermore, it has been shown that the temperature coefficient is different for different conductivities, and that the temperature coefficient is substantially proportional to the conductivity. The results of this simple law are shown by the vertical columns of the table below.

TEMPERATURE COEFFICIENTS OF COPPER FOR DIFFERENT INITIAL TEMPERATURES AND DIFFERENT CONDUCTIVITIES

Ohms per meter-gram at 20 deg. cent	Per cent conductivity	α_0	α_{15}	α_{20}	α_{25}	α_{30}	α_{50}	$-T$ "Inferred absolute zero"
0.16108	95	0.00405	0.00381	0.00374	0.00367	0.00361	0.00336	-247.2
0.15940	96	0.00409	0.00386	0.00378	0.00371	0.00364	0.00340	-244.4
0.15776	97	0.00414	0.00390	0.00382	0.00375	0.00368	0.00343	-241.7
0.15727	97.3	0.00415	0.00391	0.00383	0.00376	0.00369	0.00344	-240.9
0.15614	98	0.00418	0.00394	0.00386	0.00379	0.00372	0.00346	-239.0
0.15457	99	0.00423	0.00398	0.00390	0.00383	0.00375	0.00349	-236.4
0.153022	100	0.00428	0.00402	0.00394	0.00386	0.00379	0.00352	-233.8
0.15151	101	0.00432	0.00406	0.00398	0.00390	0.00383	0.00355	-231.3

Digitized by Google

The quantity $(-T)$ given in the last column of the above table is the calculated temperature on the centigrade scale at which copper of the particular conductivity concerned would have zero electrical resistance *provided* the temperature coefficient between 0 deg. cent and 100 deg. cent. applied continuously down to the absolute zero. The usefulness of this "inferred absolute zero temperature of resistance" in calculating temperature rise is evident from the following formula:

$$t - t_1 = \frac{R_t - R_{t_1}}{R_{t_1}} (T + t_1)$$

The presentation of the above table is intended to emphasize the desirability of determining the temperature coefficient rather than assuming it. Actual experimental determination is facilitated by the proportional relation between the temperature coefficient and the conductivity; a measurement of either quantity gives both. However, if a temperature coefficient *must* be assumed, the best value to take for average commercial *annealed* copper wire is that given in the table for 100 per cent conductivity, *viz.*,

$$\alpha_0 = 0.00428,\ \alpha_{20} = 0.00394,\ \alpha_{25} = 0.00386$$

This is the value recommended for wire wound on instruments and machines, since they are generally wound with annealed wire and experiments have shown that the distortions due to the winding of the wire do not appreciably affect the temperature coefficient.

If a value must be assumed for *hard-drawn* copper wire, the value recommended is that given in the table for 97.3 per cent conductivity, *viz.*,

$$\alpha_0 = 0.00415,\ \alpha_{20} = 0.00383,\ \alpha_{25} = 0.00376$$

The temperature coefficients in fahrenheit degrees are given by dividing any α above by 1.8. Thus, the 20 deg. cent. or 68 deg. fahr. temperature coefficient for copper of 100 per cent conductivity is 0.00394 per deg. cent., or 0.00219 per deg. fahr.

APPENDIX F. HORSEPOWER.

361 In view of the fact that a horsepower defined as 550 foot-pounds per second represents a power which varies slightly with the latitude and altitude (from 743.3 to 747.6 watts) and also in view of the fact that different authorities differ as to the precise value of the horsepower in watts, *the Standards Committee has adopted* 746 *watts as the value of the horsepower.* The number of foot-pounds per second to be taken as one horsepower is therefore such a value at any given place as is equivalent to 746 watts; the number varies from 552 to 549 foot-pounds per second, being 550 at 50 deg. latitude (London), and 550.5 at Washington. The Standards Committee, however, recommends that the kilowatt instead of the horsepower be used generally as the unit of power.

Digitized by Google

TABLE OF CONTENTS.

GENERAL PLAN.

		Paragraph
I.	DEFINITIONS AND TECHNICAL DATA	
A.	Definitions—Currents and E.M.F.'s	2 to 6
B.	Definitions—Rotating Machines	7 to 21a
C.	Definitions—Stationary Induction Apparatus	22 to 29b
D.	General Classification of Apparatus	30 to 44
E.	Motors—Speed Classification	45 to 49
F.	Definitions—Instruments	49a to 49g
G.	Definition and Explanation of Terms	50 to 63
(I)	Load Factor, Diversity Factor, Demand Factor.	50 to 51b
(II)	Non-Inductive and Inductive Load	52 to 53a
(III)	Power-Factor and Reactive Factor	54 to 56
(IV)	Saturation-Factor	57 to 58
(V)	Variation and Pulsation	59 to 63
II.	PERFORMANCE SPECIFICATIONS AND TESTS	
A.	Rating	65 to 78a
B.	Wave Shape	79 to 80
C.	Efficiency	84 to 186
(I)	Definitions	84 to 88
(II)	Measurement of Efficiency	89 to 100
(III)	Measurement of Losses	101 to 117
(IV)	Efficiency of Different Types of Apparatus	118 to 186
(*A*)	Direct current Commutating Machines	118 to 126
(*B*)	Alternating-Current Commutating Machines	127 to 135
(*C*)	Synchronous Commutating Machines	136 to 147
(*D*)	Synchronous Machines	148 to 155
(*E*)	Stationary Induction Apparatus	156 to 161
(*F*)	Rotary Induction Apparatus	162 to 167
(*G*)	Unipolar or Acyclic Machines	168 to 175
(*H*)	Rectifying Apparatus	176 to 179a
(*I*)	Transmission Lines	180
(*J*)	Phase-Displacing Apparatus	183 to 186
D.	Regulation	187 to 209
(I)	Definitions	187 to 203
(II)	Conditions for and Tests of Regulation	204 to 209
E.	Insulation	210 to 259
(I)	Insulation Resistance	210 to 213
(II)	Dielectric Strength	214 to 259
(*A*)	Test Voltages	214 to 226
(*B*)	Methods of Testing	227 to 241
(*C*)	Methods for Measuring the Test Voltage	242 to 249
(*D*)	Apparatus for Supplying Test Voltage	250 to 259

Digitized by Google

F. CONDUCTIVITY 260
G. RISE OF TEMPERATURE ..... 261 to 292
(I) Measurement of Temperature ..... 261 to 271
(A) Methods ..... 261 to 266
(B) Normal Conditions for Tests ..... 267 to 271
(II) Limiting Temperature Rise ..... 272 to 292
(A) Machines in General ..... 274 to 278
(B) Rotary Induction Apparatus ..... 279 to 282
(C) Stationary Induction Apparatus ..... 283 to 286
(D) Rheostats ..... 287 to 288
(E) Limits Recommended in Special Cases ..... 289 to 292
H. OVERLOAD CAPACITIES ..... 293 to 304

III. VOLTAGES AND FREQUENCIES

A. VOLTAGES ..... 305 to 310
B. FREQUENCIES ..... 311 to 312

IV. GENERAL RECOMMENDATIONS ..... 313 to 323

V. APPENDICES AND TABULAR DATA

APPENDIX A.—NOTATION 324
APPENDIX B.—RAILWAY MOTORS ..... 325 to 340
(I) Rating ..... 325 to 327
(II) Selection of Motor for Specified Service ..... 328 to 340
APPENDIX C.—PHOTOMETRY AND LAMPS ..... 341 to 357a
APPENDIX D.—SPARKING DISTANCES ..... 358 to 359
APPENDIX E.—TEMPERATURE COEFFICIENTS 360
APPENDIX F.—HORSE POWER 361

Digitized by Google

Digitized by Google

221

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 9

September, 1911

Per Copy, $1.00
Per Year, $10.00

UNIVERSITY OF MINNESOTA
THE LIBRARY
S '11
RECEIVED

CONTENTS

Section I. Notes and Comments

Directors' Meeting August 22, 1911 - - - - - - 257
Some of the Speeches at a Dinner Given During the Chicago Convention.
By Mr. H. M. Byllesby, Chairman of the Entertainment Committee - 258
Associates Elected - - - - - - - - 265
Applications for Election - - - - - - - 267
Students Enrolled August 22, 1911 - - - - - - 267
Award of the John Scott Medal - - - - - - - 268
San Francisco Meeting and Japan Excursion of Mining Engineers - 269
Personal - - - - - - - - - 269
Obituary - - - - - - - - - 270
Library Accessions - - - - - - - - 270

Section II. Papers, Discussions, and Reports

Discussion on "Comments on Fixed Costs in Industrial Power Plants," and "The Cost of Industrial Power," New York, March 10, 1911 - 1957
Responsibilities of Electrical Engineers in Making Appraisals. By H. M. Byllesby, Chicago, June 27, 1911 - - - - - - 2013
Engineering Specifications. By Frank F. Fowle. Chicago, May 11, 1911 - 2029

Index to Advertisements - - - - - - - iii

Copyright 1911, by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y. December 17 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

FOUR NEW BOOKS

352 Pages 6 x 9 Inches 139 Illustrations Net $3.00

Electric Central Station Distribution Systems

Their Design and Construction

By

HARRY BARNES GEAR, A.B., M.E.

Associate Member American Institute of Electrical Engineers

and

PAUL FRANCIS WILLIAMS, E.E.

Associate Member American Institute of Electrical Engineers

---

188 Pages 6 x 9 Inches 101 Illustrations Net $2.00

Design of Static Transformers

By

H. M. HOBART, M. Inst. C. E.

---

330 Pages 6 x 9 Inches 76 Illustrations Net $3.00

The Propagation of Electric Currents

In Telephone and Telegraph Conductors

By

J. A. FLEMING, M.A., D.Sc., F.R.S.

---

318 Pages 5½ x 8 Inches 127 Illustrations Net $2.50

Electric Traction and Transmission Engineering

By

SAMUEL SHELDON, A.M., Ph.D., D.Sc.

Professor of Physics and Electrical Engineering at the Polytechnic Institute of Brooklyn, and Past-President of the American Institute of Electrical Engineers

and

ERICH HAUSMANN, E.E., M.S.

Instructor in Physics and Electrical Engineering at the Polytechnic Institute of Brooklyn, and Associate of the American Institute of Electrical Engineers

---

D. VAN NOSTRAND COMPANY

Publishers and Booksellers

23 Murray and 27 Warren Streets New York

Digitized by Google

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of
THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies.
All other countries $12.00 per year
Single copy $1.00
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX **September, 1911** No. 9

Directors' Meeting August 22, 1911

A special meeting of the Board of Directors of the A.I.E.E., was held at the Institute headquarters, 33 West 39th St., New York, on Tuesday, August 22, 1911. The following Directors were present: Gano Dunn, Ampere, N. J.; H. W. Buck, New York City; P. H. Thomas, New York City; D. B. Rushmore, Schenectady, N. Y.; W. G. Carlton, New York City; Charles W. Stone, Schenectady, N. Y.; A. W. Berresford, Milwaukee; Henry H. Norris, Ithaca, N. Y.; S. D. Sprong, New York City; H. H. Barnes, Jr., New York City; W. S. Rugg, New York City; N. W. Storer, Pittsburgh; W. S. Lee, Charlotte, N. C.; Farley Osgood, Newark, N. J.; G. A. Hamilton, Elizabeth, N. J.

Three hundred and sixty-three delinquent members were ordered dropped from membership in the Institute.

Upon recommendation of the Board of Examiners fifty-nine applicants were elected Associates, and seventy-nine applicants were enrolled as Students. The following Associates were transferred to the grade of Member: Orin B. Coldwell, Portland, Ore.; Lucius B. Andrus, South Bend, Ind.; Milton W. Franklin, Schenectady, N. Y.; M. de Chatelain, St. Petersburg, Russia; Charles d'Ornellas, Buenos Aires, A. R.

Petitions were considered from members in Vancouver, B. C. and Lynn, Mass., for authority to form Sections, and upon the recommendation of the Sections Committee the authority was granted.

The report of the committee recommending a change in the method of nominating officers of the Institute was considered, and in order to give it further consideration it was ordered to be brought up at the October or November meeting.

President Dunn announced the appointment of the Institute committees and representatives for the present administrative year. A list of these appointments will be found elsewhere in this issue.

The Board elected the following three members of the Board of Directors to serve upon the Edison Medal Committee for two years: Lewis B. Stillwell, H. H. Barnes, Jr., and S. D. Sprong. The Board also confirmed the appointment by the President of Frank J. Sprague and Schuyler Skaats Wheeler as members of the Edison Medal Committee for terms of five years.

The following resolution was adopted:

Resolved, That the Committee on Conservation of Natural Resources be discontinued and the President be authorized to appoint a committee of seven on Public Policy. The duties of this Committee shall be to report to the Board on such questions of Public Policy as the Board shall refer to it, and to call the attention of the Board to such other matters of Public Policy as the discretion of the Committee prompts.

The personnel of this committee is given on another page of this issue.

The following resolutions were adopted:

Resolved, That it is the sense of the Board of Directors that it would be desirable to hold an International Electrical Congress during the Panama Exposition in San Francisco in 1915, and that such a Congress be initiated and conducted by the American Institute of Electrical Engineers under the authority of the International Electrotechnical Commission.

Resolved, That in furtherance of the project to hold an International Electrical Congress during the Panama Exposition at San Francisco in

Digitized by Google

1915, a committee on Congress organization be authorized, the members of same to be appointed by the President after receipt of such information from the International Electrotechnical Commission as would indicate a disposition on its part to authorize the American Institute of Electrical Engineers in the holding of such a Congress.

Upon the invitation of the officers of the American Mining Congress, to be held in Chicago September 26–29, 1911, the Board authorized the President to appoint two delegates to represent the Institute at this Congress. The President appointed Messrs. Peter Junkersfeld and William B. Jackson, of Chicago.

The following resolution was passed:

Resolved, That the Board of Directors at this meeting is inclined to view favorably the project of an Institute trip to Panama in January or February, and the President is hereby authorized to appoint a committee, in co-operation with the Meetings and Papers Committee, to make final recommendations thereon at the October meeting of the Board.

The President appointed Messrs. S. D. Sprong, Chairman, A. W. Berresford, F. L. Hutchinson, P. Junkersfeld, H. A. Lardner, W. S. Rugg, D. B. Rushmore, Edward Schildhauer and A. M. Schoen.

The question of a suitable acknowledgement of the gift of a bronze bust of von Helmholtz by Mr. Edward D. Adams was referred to the President with power.

There was also adopted the following resolution:

Resolved, That it is the sense of the Board of Directors that a larger measure of publicity be given to the Institute's affairs, and that properly edited resume of the actions of the Board be sent after each meeting to the technical press.

Questions as to what matter shall be included in this resume to be left to the discretion of the Secretary with the approval of the President.

The committee appointed at the meeting of the Board held at the Chicago Convention to canvass the candidates for Secretary and report to the Board, presented the following resolutions, which were adopted:

Resolved, That the Board of Directors hereby appoints Mr. F. L. Hutchinson Acting Secretary in place of Mr. Ralph W. Pope, resigned, to act as Secretary from this date in all duties devolving upon that official under the Constitution of the Institute, and authorizes him to draw and countersign all checks and drafts in payment of bills and vouchers approved by the Finance Committee and endorsed by the Treasurer, as provided in Section 42 of the Institute Constitution. Mr. Hutchinson's services as Acting Secretary are to continue until the end of Mr. Pope's unexpired term, August 1, 1912, or until the earlier appointment of a Secretary by the Board.

Resolved, That as the President is about to go abroad to represent the Institute at the meeting of the International Electrotechnical Commission and the International Electrical Congress, he is hereby authorized to add a fourth member to the Secretary Committee and to delegate the chairmanship to one of the present members.

President Dunn appointed as the fourth member of the Secretary Committee Mr. John J. Carty, and delegated Mr. H. W. Buck to act as Chairman.

Resolved, That it is the decision of the Board that that portion of last year's proposed amendments to the Constitution providing for the appointment of the Secretary by the Board, instead of his election by the membership, should be again submitted to the membership for action at the proper time this year.

President Dunn announced that during his absence matters requiring the attention of the President should be referred to Vice-President H. W. Buck.

Some of the Speeches at a Dinner Given During the Chicago Convention by Mr. H. M. Byllesby, Chairman of the Entertainment Committee

On Thursday evening, June 29, during the convention of the Institute at Chicago, Mr. H. M. Byllesby, chairman of the entertainment committee, gave a dinner to 60 representative capitalists, men of affairs, publishers, and officers and members of the American Institute of Electrical Engineers, in expressing a hospitable welcome to Chicago. The speeches at this dinner bore upon important industrial and conservation questions, in which the Institute has a deep interest. They have been published in a particularly attractive typographical form and presented as souvenirs to the guests at the dinner. Space will not permit the reprinting of the brochure in full, but it is thought the membership may be interested in the

Digitized by Google

introductory address of Mr. Byllesby, and the replies of President Jackson and President-Elect Dunn.

The Board of Directors at its meeting on August 22 voted to establish a committee on Public Policy, the personnel of which is printed in the lists of committees announced in this issue.

Address of Mr. Byllesby.

Fellow members of the American Institute of Electrical Engineers and our guests.—

It is now my privilege to call you to order for the purpose of introducing those who will honor us by making addresses. A few moments ago in speaking with Mr. Forgan, I explained that I knew pretty well what I wished to say this evening, but that I was puzzled to know exactly how to begin. Mr. Forgan stated that when at school in Scotland, the schoolmaster ordered him to write an essay on a certain subject. Mr. Forgan said that he found it very difficult after repeated efforts to make a proper beginning. His schoolmaster came to his assistance and suggested that he commence as follows:— "In the long annals of humanity, both sacred and profane—" (*Laughter.*)

This appealed to me as a fitting commencement to the few remarks I am privileged to make. So I state that "in the long annals of humanity, whether sacred or profane," there has probably been no parallel to the wonderful development of the science of electrical engineering during the past generation and that the achievements of the electrical engineer in the last thirty to thirty four years outstrip the achievements of any other branch or department of modern industry or modern efforts.

As a member of the American Institure of Electrical Engineers, I take pride in the glory which now properly surrounds our profession. I feel, however, this evening that while enjoying properly what we believe to be the well earned and we hope the well merited applause which our achievements have earned, we should not forget that an extremely important feature in enabling us to accomplish these achievements without which many of our victories would not have been realized, has been the continued presence with our profession, the continuing and necessary help of the capitalist, the commercial man, the man of affairs. Let us not forget that in the struggling period of the earlier development of our art, when frequent disappointments attended the crudity of our work and inventions, the man with capital and with faith in the possibilities of our inventions and developments, was present with us to carry us through these periods of distress and temporary disaster and disappointment.

During the present week there has been held in our city, the twenty eighth annual convention of the American Institute of Electrical Engineers. This society includes in its membership the names of Edison, Shallenberger, Thompson, Stanley, Westinghouse, Sprague, Vandepoele, Rice and many others whose devoted service and brilliant achievements have given to it an enduring fame. We have with us this evening Mr. Sprague, Mr. Arnold, Mr. Rice, Professor Scott, Professor Jackson, Professor Goss, Professor Crocker, Doctor Wheeler, Mr. Ferguson, Mr. Junkersfeld, and others who have done and are doing work of brilliant and profound usefulness in the various departments covered by the profession of the electrical engineer. It is my privilege to have present as my guests on this occasion many members of the Institute who in their earlier days had close and intimate professional and business relations with me and it is with unusual pleasure and with great personal gratification that I welcome them.

A long experience has taught me the close interdependence of our profession and capital—the necessarily close relationship between the men of our profession and the business men, the men of capital, the men of finance. Our profession could not exist without these men,

Digitized by Google

and these men would lose a large and profitable use for their abilities and resources without the efforts and the partnership and the genius of the electrical engineer. It seemed to me, therefore, altogether fitting and proper—I hope as great a pleasure to you gentlemen of the electrical engineering profession as to myself—to be able to bring you into close and friendly contact this evening with my friends of our great city whose profession is that of commerce, of finance and the utilization of capital in the continuing upbuilding of our great country and its manifold and diverse interests. Principal among these and in increasing proportions has become the products of the brains and industry of the electrical engineer. I may be pardoned if I call the attention of all of you gentlemen present to what seems to me to be a decidedly remarkable gathering here of the leaders of one of the foremost professions oft he world, and the foremost men of commerce, of capital, of finance, of transportation, of the press and pulpit, of the most progressive of our American cities.

For some time there has been a growing tendency in the United States of America and generally in the world at large towards a condition of unrest, of dissatisfaction, as between brains, labor, and capital, and while I am professionally an optimist, I cannot but feel that the present situation with its new and profound problems crying for a solution, is a situation fraught with the most serious possibilities, surely so if the present condition of unrest is allowed to continue and drift in its present unmistakable directions. On the other hand I am hopeful that by timely effort, by manly and candid recognition of the demands of the times—a sincere effort to solve the problems of our modern civiliz ation which are demanding a solution—that out of the present unrest and turmoil a condition may be evolved of fairness and justice, a condition of greater tranquillity and greater humanity than has previously existed.

I believe it has become the duty of every serious minded man, no matter in what calling in life, no matter in what walk of life his activities may find themselves, to seriously consider the present condition and to do everything that in him lies toward a fair and just and wise solution of the problems of the times. By doing this we can hope to better the conditions which surround our civilization. If we fail to make the effort we shall have no one to blame but ourselves—if in the undirected trend of passion resulting from ignorance or injustice, misapprehension or selfishness our country drifts to the cataclysm of an economic or social revolution. We can view this situation as we please—we can adopt the doctrine of *laissez faire*—we can adopt the selfish doctrine of each man looking after his immediate interest or we can adopt the far manlier and more worthy course of recognizing these problems and difficulties of the times and by drawing closer together the three great moving forces of modern life—labor, brains and capital—to endeavor to direct thought and legislation and to bring about a condition more worthy of the great opportunities possessed by civilized humanity today. I believe that the gentlemen present here this evening will adopt this latter course and will look forward with hopefulness into the clouds which are at present surrounding the horizon.

Reply of President Jackson

Mr. Byllesby and Gentlemen.—

I cannot say many words to you on account of the fact that I am already past due at an important meeting of the delegates of the American Institute of Electrical Engineers who have come from all parts of the land, and indeed, from other lands, for the purpose of discussing the policy of that Institute, but I will say a few echoes from my opening address of Tuesday morning to the convention of the Institute. Before taking up the thread of this, however, I wish to express the delight, pleasure

Digitized by Google

and satisfaction which the Institute has had in coming to Chicago for its annual convention. Your great city possesses as two of its distinguished citizens past presidents of the American Institute of Electrical Engineers. One of these past presidents is Mr. L. A. Ferguson, whom we are fortunate in having for Chairman of the Committee of Arrangements for this convention. You all know Mr. Ferguson, but I want to say that he is a man unique in this country. He is one of the most distinguished central station engineers that we have; he is the only man in the world who has held the presidency of the three great influential electrical engineering societies. He is past president of the American Institute of Electrical Engineers, past president of the National Electric Light Association, and also past president of the Association of the Edison Electric Illuminating Companies that have done so much in advancing the interest and the welfare of the people who need artificial illumination. It is hardly necessary for me to say to you that Mr. Ferguson is the man who has charge of the engineering and operation of your Commonwealth Edison Company and the man who supports so loyally and so successfully the magnificent imagination of the remarkable president of that company.

Another of our past presidents who is your fellow citizen is Mr. B. J. Arnold, notable for his great work in electric railways and for having been your counselor and representative in the rehabilitation of your surface railway system.

Gentlemen, the American Institute of Electrical Engineers is proud to hold its annual convention in a city which may boast of these two past presidents as its citizens.

Again, no city but Chicago could provide Mr. Henry M. Byllesby as Chairman of the Entertainment Committee of the Convention, and I wish at this point to express my appreciation not only of Mr. Byllesby's services for the convention, but also for the entertainment of this evening which is aside of the formalities of the Convention.

I could continue this enumeration of your eminent citizens who are members of our Institute, and it would afford to me great pleasure to do so and I am sure would add to your interest, but the pinch of time prevents. I will only say that our Institute includes the great administrators and engineers of nearly all of your electrical companies.

Now, I will turn to the real thread of my speech. I will have to speak rapidly on account of the press of time. I am going to speak of the philosophical side of my opening address of Tuesday morning. In some respects Mr. Dawes in his interesting speech just concluded has taken the thread of my discourse. He has said that it is time for men of business to annex their own. I was about to say that it is time for engineers to annex their own; the point being that the great industries of the world are fundamentally due to the inventions of engineers. The industries include not only manufacturing processes, but also the agencies of transportation and intercommunication—the railroads, the telephones, and the telegraphs—and in addition to all that, the industries also include our great systems of artificial illumination and the distribution of electrical power, for the further development of which so much effort is now being expended and in which development there is so much advantage coming for the people of the nation. The engineers through their inventions and work have made all of those things, with the aid, gentlemen, of yourselves, who are men of imagination, courage and money.

In executing this work of development an incorporated company of stockholders has become a necessity. The corporation is merely a natural selection. It is the survival of the fittest in the process of making useful the great inventions of the world. It is a perfectly natural development from the one-man business and the small partnership to the extensive organiza-

Digitized by Google

tions which are found in corporations. This direction of development is a necessity for meeting the requirements of the day. Speaking of it reminds me of the name of the philosopher, Herbert Spencer, who remained a bachelor throughout his life for the purpose of writing a series of books in which is elaborated a great system of philosophy in which he asserts that development goes on from the homogeneous into the heterogeneous. He points out that the highest development is in the form of definite, coherent heterogeneity. Now, that is one of the characteristics of the great corporations. They are organized upon definite, coherent principles, but are sufficiently heterogeneous in their personnel so that they can meet the needs in serving our present-day requirements.

A nation immersed in pursuits of peaceful industry becomes strong in the capacity for working out its development by means of evolutionary processes. That is the manner in which we are now working out our pathway as a nation. We are developing along evolutionary lines and the modern giant corporation follows in the wake of the one-man business and the simple partnership in response to an inextinguishable natural law. This is a case of natural selection. The progress of corporation development cannot be prevented. It is one of the manifestations accompanying improved means of speedy transportation and intercommunication. Of the influence of the latter agencies, the learned and distinguished historian, Macaulay says, "Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilization of our species. Every improvement of the means of locomotion benefits mankind morally and intellectually as well as materially, * * *."

The possibility of, and indeed a necessity for, great corporate organizations came in the train of leading improvements in the means of locomotion and other beneficial inventions which abridge distance and subjugate time. Men of this age do not desire to relinquish the benefits of the improvements. We must, therefore, adjust our mental attitude to dealing properly with the situation; and in making the adjustment we must return to the old and approved recognition that a misdeed is a personal thing, and remember that responsibility for it cannot be shifted from the personality of the man in responsibility to an impersonal aggregation entitled a corporation which he manages. In early days when English kings had great prerogatives in the government, and the doctrine of divine right, associated with the doctrine that the king can do no wrong, were still extant, the king was nevertheless limited to an administration of the affairs of the realm conducted, history tells us, in accordance with the laws, and, in case he broke those laws, his advisers and agents were held responsible, and they were made personally answerable to the courts. History also indicates that this personal answerability of the advisers and agents had a tremendous influence on the conduct of government and its relations to the public. In building up our industrial structure we must not overlook the plain guide board of history, and personal answerability must be established. But if we must establish personal answerability *to* the public, we must also establish fair and generous dealing *by* the public.

The building up of a great industrial nation in an honorable state of civilization is subject to many hazards—an error may cause injury to the structure that takes years or even decades to eradicate. It is, therefore, desirable to go cautiously and utilize the mature reflection of straight-thinking men who will give their thought to the subject. Here is one of the places where the engineers are not to put their efforts along side of the efforts of the capitalists and investors. Corporations must be treated generously and established in confidence

Digitized by Google

or they can not give generous service to the people who need their service and whom they were formed to serve.

Those great inventions to which Macaulay refers in the quotation which I just made are wanted by the people of the nation, and they cannot be established and made most useful except through great corporations of the type I have referred to. This being true, it is manifest that in working out the welfare of our nation, it is a matter of the greatest importance that fair dealing shall be done towards those corporations as completely as by the corporations. It is here that it seems to me the engineers have a field of usefulness and a duty to the nation and public which they have not properly cultivated. We are acquainted with the facts in regard to the public service corporations and other like corporations of the land, and it is for us who are supposed to be right-minded straight-thinking men to aid in finding the path which shall lead to fair dealing for one and all.

Now, gentlemen, I must take myself away to the engagement previously referred to. I am sorry that duty makes this necessary. I thank you very much for your kind entertainment of this evening, and particularly I wish to express my pleasure and thanks to our host, Mr. H. M. Byllesby.

REPLY OF PRESIDENT-ELECT DUNN

Mr. Byllesby and gentlemen:

When I first came here this evening and was confronted with so many distinguished representatives of capital in this remarkable city which is said to be able to make water run up hill, or at least backward and rob Niagara Falls of eight per cent of its glory, I felt nervous. In the depths of a wonderful table I saw limped pools where fountains spurted ultra-violet water and goldfish assaulted argosies, where falls dashing over rocks, turned themselves most obediently into electric power, operating by high tension lines so perfect an electric railroad that even Mr. Sprague and Mr. Arnold had to sit up and take notice.

The railroad had a way of bowing to the chairman, and there was a mysterious rose in the ceiling, half hidden occasionally by a dashing aeroplane.

Realizing that we, a group of knights of the slide rule and of the hyperbolic function, had been lured to this narrow enclosure and surrounded in a way to make egress difficult, thoughts of the Mamelukes crossed my mind, and when the exercises began with prayer I could not tell what was going to happen and was prepared for the worst.

But Alladin, our host, has reassured me and at his call I rise to an agreeable occasion. These formidable representatives of the great metropolis are not so different from ordinary men after all. They are just great and good fellows here giving a cordial and most hospitable reception to the visiting members of the American Institute of Electrical Engineers.

So much that was engineering was said by President Jackson and so much that indicates his innate characteristics as an engineer has just been said by Mr. Insull, that I regard engineering as having been well represented at this dinner and I feel I may speak on the subjects discussed by Mr. Dawes and Mr. Reynolds, in which I take a particularly deep interest as an American citizen.

We are in the midst, unquestionably, of a confused situation in the industrial development of our country, but I second most heartily the sentiments of Mr. Reynolds when he expressed his confidence in the ultimate satisfactory outcome of the difficulties that now surround us. I share also, the optimism of Mr. Dawes when he feels that in the long run something right will come out of all this confusion.

If I may presume to speak for the highbrows here present—with whom I hope I may have the honor of being classed—and with particular reference to the problems of electrical development as affected by the present state

Digitized by Google

of affairs, I am sure they will agree that the situation is one in which a proper solution can be obtained only by the coöperation and joint discussion of men of different kinds of minds, all of a high order of ability.

We are assembled as representatives of two different classes. We, Mr. Byllesby, may be regarded as the conductors; you and your friends, the "juice," and we are mutually necessary to each other.

We technical men develop in our own spheres with not enough contact with the constructive organizers of the forces of capital. This dinner upon which so much successful effort has been spent will accomplish results out of all proportion to that effort if it serves no other purpose than to bring together two rather essentially different types of men and to make each of them feel a greater confidence in the other.

In a certain sense all citizens of the United States are from Missouri. They want to be shown, and when shown will do the right thing.

We have allowed the mob, the ignorant, the prejudiced, too long to dominate our national policies, too long to occupy the arena of public life, too long to shape the sentiments that rule our government, and it is upon us, educated men, selected men of the kind assembled here from different callings to get together and contribute our share of pointing the way out of our national difficulties.

We are like Dante and Virgil in the dark valley, but there is for us just as certainly a way out as there was for them, and if I may plagiarize from Mr. Dawes, what we need is brains and information.

With an alliance of the kind of brains and information gathered here to-night there can be but one outcome.

If I may be bold enough in an assemblage of practical and executive men to quote from a literary person, to take a leaf from a book of Matthew Arnold, I would say, "Might rules until right is ready." This is but the statement of a principle the truth of which you already recognize.

The real difficulty at present is not so much from forces that are opposing the development of the industries of our country, as from the fact that there is not an altogether clear and agreed upon policy formulated and announced by the other side.

Gentlemen, the American Institute of Electrical Engineers for which as President-elect I have the honor of speaking stands ready to formulate and contribute that portion of the solution of the problem that relates to the physical and practical difficulties in the way of the developments of electrical properties.

It stands ready to solve the things relating to the laws of nature that have to be solved before the things relating to the laws of men can be solved by you men of capital and affairs.

Whether the hen or the egg was first is a question that I think has not yet been definitely settled. My own opinion is that it was the highbrow who first pulled the leg of the capitalist and not the capitalist who first got out and sought the inventor, but without controversy as to which of our respective classes leads, or is the most important, the fact that these two classes are here so prominently represented is an auspicious omen.

Once they get together once it becomes appreciated that practical sense and technical knowledge, that brains and information have been put to work, once the intellectual forces here represented are allied, nation wide evils will dissolve and result cannot for a moment be in doubt.

What we most need now is to formulate ideas. Wealth in all ages has had tremendous power. From ancient times down to the present it has seemed to be the mainspring of civilization, but there is a greater power than wealth—the power of ideas.

The idea of Christianity, the idea of the Declaration of Independence, the idea of many of the great movements

Digitized by Google

that have swept over the world, have in the end accomplished things which wealth's power to accomplish would have been almost insignificant.

I feel I am not assuming too much, if on the part of the American Institute of Electrical Engineers, I assure you that they will contribute their share of the ideas, which, with yours, will release the irresistible force that will clear the way and enable the United States of America to continue to lead the industrial world.

Associates Elected August 22, 1911

ATKINSON, EMBRY SWEAMIGEN, Chief Draftsman, Fairbanks, Morse Electrical Mfg. Co., 21st & Northwestern Ave., Indianapolis, Ind.

BARTLETT, FRED JOHN, Power Apparatus and Supply Salesman, Western Electric Co., Omaha; res., 808 D St., Lincoln, Neb.

BEHRENS, EDWARD LESLIE, Foreman, Canadian General Electric Co., Toronto, Ont.

BLAKESLEE, DORAF WILMOT, Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg; res., 1032 Ross Ave., Wilkinsburg, Pa.

BROWN, FREDERICK BAYLIS, Consulting Engineer, with Walter J. Francis, 24 Commercial Union Bldg., Montreal, Quebec.

BRUEN, GEORGE EVERETT, Superintendent Electrical Department, National Board of Fire Underwriters, 135 William St., New York City.

BRUMELLE, HARRY ELSON, General Foreman of Meter Dept., United Electric Light & Power Co., 519 West 146th St., New York City.

BUCKARD, CHARLES ALTON, Transmission Engineer, Bell Telephone Co. of Canada, Ltd., Montreal, Que.

CAMPBELL, JAMES JOSEPH, Joint Manager, Kilmer Pullen & Burnham, Ltd., 11 St. Sacrament St.; res., 78 Union Ave., Montreal, Que.

CASE, HOWARD T., Technical Writer, Publication Bureau, General Electric Co.; res., 106 Union St., Schenectady, N. Y.

CHERRY, LOUIS BOND, Engineer and Salesman, Electrical Department, H. W. Johns-Manville Co.; 251 3rd Ave., So. Minneapolis, Minn.

CLARK, LEON L., Electrical Engineer, Waddell & Harrington, 1012 Baltimore Ave., Kansas City, Mo.

COLMAN, WILLIAM HENRY, District Manager, Supply Dept., General Electric Co., Chicago; res., Park Ridge, Ill.

DICKIESON, ARTHUR LOGAN, Canadian General Electric Co.; res., 215 Simcoe St., Peterboro, Canada.

DOUGLAS, JAMES ATKINSON, Electrical Engineer, Canadian Pacific Railway, Winnipeg, Man.

EDKINS, ERNEST ARTHUR, Secretary Advisory Committee, Commonwealth Edison Co.; res., 847 Montrose Blvd., Chicago, Ill.

EISENMENGER, HUGO EMIL, Electrical Engineer, National Electric Lamp Ass'n., 4411 Hough Ave., Cleveland, Ohio.

ENGLISH, WILLIAM JAMES, Secretary and General Manager, Commercial Utilities Mfg. Co.; res., 101 West 48th St., New York City.

FITZPATRICK, FRANCIS J., Electrical Inspector, Department of Water, Gas & Electricity, 531 Tremont Ave., Bronx, N. Y.

GENT, EDGAR WALTER, Electrical Engineer, Electrical Alloy Co., 48 Water St.; res., 213 Speedwell Ave., Morristown, N. J.

GLAFKE, CHARLES CLYDE, Electrician, 168–170 Second St., San Francisco, Cal.

GRAF, ROBERT J., Secretary, H. M. Byllesby & Co., 206 La Salle St.; res., 7030 Euclid Ave., Chicago, Ill.

GROSS, JOHN HENRY, Park Engineer, Board of Park Commissioners, Druid Hill Park; res., 2502 Guilford Ave., Baltimore, Md.

Digitized by Google

HENSCHEL, OTTOMAR HENRY, Student, Marquette University Milwaukee; res., 1918 N. 6th St., Sheboygan, Wis.

HODGE, WILLIAM HENRY, Manager Publicity Department, H. M. Byllesby & Co., 206 South La Salle St., Chicago, Ill.

HOWARD, CHARLES D., Secretary, Pure Carbon Co., Wellesville, N. Y.

JOHNSON, EDWIN, Electrical Engineer, All-Svenska Elektriske A. B., Westeras, Sweden.

JOHNSTONE, ROY JAMES, Chief Electrician, Creston Colorado Co., Torres, Sonora, Mexico.

KELLY, ANDREW PARK, Cadet Engineer, Northern Indiana Gas & Electric Co., Hammond, Ind.

LIGHTFOOT, EDWIN NIBLOCK, Engineer, Cutler-Hammer Mfg. Co., 144th St. & Southern Boulevard; res., 770 Union Ave., New York City.

MACNIDER, JAMES STANLEY, Civil Engineer, Westphal, King & Ramsay, Ltd., Shanghai, China.

MCKOWEN, FRANK LESLIE, Assistant to Distribution Superintendent, Victoria Falls & Transvaal Power Co., Ltd., Germiston, Transvaal, S. A.

MERRITT, ROBERT ALONZO, Assistant Power Engineer, Toronto Electric Light Co., Ltd.; res., 574 Church St., Toronto, Canada.

MILLS, ERNEST ARTHUR, Chief Technical Assistant Engineer, Yorkshire Electric Power Company, Thornbull, Dewsbury, Eng.

MORAY, ARCHER FRANKLIN, Erecting and Operating Dept., Trenton Electric & Water Co., Trenton, Ont.

MYRICK, GEORGE HAROLD, Electrical Engineer, Minerallac Electric Co., 400 So. Hoyne Ave., Chicago, Ill.

NEUMAYER, ANTHONY, Electric Meter Man, St. Clair County Gas & Electric Co.; res., 125 S. Chestnut St., Belleville, Ill.

OBERMILLER, JAMES ARTHUR, President and General Manager, States Electric Co., 24 S. Clinton St., Chicago, Ill.

PACK, ROBERT FRANCIS, Secretary and Comptroller, Toronto Electric Light Company; res., 165 Roxborough St., East, Toronto, Ont.

PAULSEN, MARSHALL HENRY, Electrician, Geo. W. Jackson Co., 756 W. Jackson Blvd.; res., 847 Read Court, Chicago, Ill.

PORTLEY, JOHN J., Assistant to Electrical Superintendent, Fort Smith Light & Traction Co.; res., 718 No. 6th St., Fort Smith, Ark.

QUALLS, WILLIAM FRANKLIN, General Manager, Decatur County Independent Telephone Co., Greensburg, Ind.

RAVEN, HARVEY WILLIAM, Electrician, 7302 Carpenter St., Chicago, Ill.

REILLY, FRANK C., Manager Electrical Department, H. W. Johns-Manville Co., 72 Jefferson Ave., Detroit, Mich.

RICHARDSON, CHARLES RITTER, Draughtsman, Edison Electric Illuminating Co., Boston; res., Scituate, Mass.

ROGERS, CLARENCE ELLAMS, Cable Tester, Bay Cities Home Telephone Co., Oakland, Cal.

RUTLEDGE, HENRY HILL, Wireman, Stone & Webster Engineering Corporation; res., 307 South 9th St., Minneapolis, Minn.

RYAN, JAMES TILLMAN, Cost Clerk, J. G. White & Co., 334 California St.; res., 2051 Golden Gate Ave., San Francisco, Cal.

SCHERNER, JOHN, Mechanical Engineer, Federal Rubber Manufacturing Co., Cudahy; res., 611 Ellen St., Milwaukee, Wis.

STANNARD, H. HOWARD, Commercial Engineer, with G. M. Gest, 277 Broadway, New York City.

SULLIVAN, PATRICK FRANCIS, Electrician, Geo. W. Jackson Co., 756 W. Jackson Blvd.; res., 6385 Loomis St Chicago, Ill.

SUTTON, GROVER CLEVELAND, Electrical Engineer, Panhandle Lbr. Co., Spirit Lake, Idaho.

TAKAHASHI, MOTOE, Chief Electrical Engineer, Ashio Copper Mines, Tokio Japan.

Digitized by Google

TOEPPEN, MANFRED KURT, Inspector Line Department, United Railways Co., of St. Louis, 3869 Park Ave., St. Louis, Mo.

VIANNA, JOHN GEORGE, Electrical Engineer, Rio de Janeiro Light & Power Co., Rio de Janeiro, Brazil.

VINSON, S. GLEN, Secretary and General Manager, Ideal Eelctric & Mfg. Co., Mansfield, Ohio.

WAGNER, EFFINGHAM BUCKLEY, Assistant Electrical Engineer, Lehigh Valley Coal Co.; res., 56 N. Washington St., Wilkes-Barre, Pa.

WALBRIDGE, JOHN TUTHILL, Consulting Engineer, John T. Walbridge Engineering Co., 705 Pullman Bldg., Chicago, Ill.

WHEATON, ALBERT JOSEPH, Superintendent, Mitchell-Gray Electric Co., 259 Smith St., Winnipeg, Manitoba.

Total, 59.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before September 25, 1911.

10624 Alden, L. R., Baltimore, Md.
10625 De Vilbiss, E. B., Ft. Wayne, Ind.
10626 Greenwald, G., St. Petersburg, Russia.
10627 Hussey, H. A., East Orange, N. J.
10628 Krause, G. W., Detroit, Mich.
10629 McKeen, F. S., Seattle, Wash.
10630 Nordensvan, G. M., Reno, Nev.
10631 Richardson, G. W., Kashmir State, India.
10632 Rosenthal, H., Philadelphia, Pa.
10633 Tifft, G. L., Wauwatose, Wis.
10634 Volio, J. J., San Jose, Costa Rica.
10635 Dunbar, G., Seattle, Wash.
10636 Fennessy, D.V., Parral, Chih., Mex
10637 Keeney, W. E., Seattle, Wash.
10638 Dewhurst, J.A., Schenectady, N.Y.
10639 Polhemus, L.E., Guanajuato, Mex.
10640 Van Dyke, C.S., Schenectady, N.Y
10641 Stocks, B. R., Pittsfield, Mass.
10642 Steinicke, F.H., Schenectady, N.Y.
10643 Howe, C. F., Macon, Ga.
10644 Ehmke, H.C., Jr.. Rock Island, Ill.
10645 Long, R. H., Pinawa, Man.
10646 Reed, H. P., Milwaukee, Wis.
10647 Kenney, W. C., Flint, Mich.
10648 Henning, C.S., Jr., Richfield, Idaho
10649 Broggini, A., Lakewood, Ohio.
10650 Church, S. E., Chicago, Ill.
10651 Daniels, A. M., San Francisco, Cal
10652 Glander, E. L., Aberdeen, S. D.
10653 Hanser, J. E., Cleveland, Ohio.
10654 Hayden, T. J., New York City.
10655 Hershey, H. E., Chicago, Ill.
10656 Kremer, W. R., Milwaukee, Wis.
10657 Pfeifer, J. W., Forest Park, Ill.
10658 Serva, A. A., Fort Wayne, Ind.
10659 Tucker, W. H., New York City.
10660 Ahlstrom, W., Chicago, Ill.
10661 Berry, E. R., Malden, Mass.
10662 Birks, L., Wellington, N. Z.
10663 De Blois, T. M., Toronto, Ont.
10664 Gebhardt, C. W., San Francisco.
10665 Lindem, M., Milwaukee, Wis.
10666 McHenry, M. J., Toronto, Ont.
10667 Stanley, J., Trinidad, Colo.

Total, 44.

Students Enrolled August 22, 1911

4442 Shepherd, W. A., Mass. Inst. Tech.
4443 Novoa, G., Georgia Schl. of Tech.
4444 Hoeveler, J. A., Univ. of Wisconsin
4445 Blythe, W. E., Stevens Inst. Tech.
4446 Meyerherm, C. F., Stevens Inst. Tech.
4447 Warner, M. F., Cornell Univ.
4448 Schluderberg, C., Cornell Univ.
4449 Alcorn, E. B., University of Iowa.
4450 Johnston, A. L., Univ. of Colorado.
4451 Giroux, R. M., Univ. of Colorado.
4452 Hart, A. P., Univ. of Colorado.
4453 Finley, R. B., Univ. of Colorado.
4454 Hansen, M. J., Univ. of Minn.
4455 Coley, W. R., Worcester Poly Inst.
4456 Thomas, R. E., Penn. State Coll.
4457 Scherer, W.W., Poly.Coll. of Engg.
4458 Alexander, J. F., Univ. of Wis.
4459 Kergerreis, R., Ohio State Univ.
4460 Feinberg, A., Harvard Univ.
4461 Taylor, F. C., Mass. Inst. of Tech.
4462 Haines, J. M., Penn. State College.

Digitized by Google

4463 Caldwell, W., Univ. of Kansas.
4464 Hague, F. T., Univ. of Pittsburg.
4465 Kinsman, R. E., Columbia Univ.
4466 Moore, J. R., Univ. of Pittsburg.
4467 Simon, R. J., Univ. of Pittsburg.
4468 Carrico, H.E., Worcester Poly. Inst.
4469 Rachofsky, M. O., Univ. of Col.
4470 Reed, C. S., Univ. of Pittsburg.
4471 Leerberg, N., Iowa State College.
4472 Wiley, W. R., Penn State College.
4473 Cummer, A. W., Colo. Agr. Coll.
4474 Good, H. F.. Iowa State College.
4475 Platts, C. E., Univ. of Oregon.
4476 Brooks, E. C., Iowa State College.
4477 Glover, C. Van C., Ga. Schl. of Tech.
4478 Chapman, A. G., Univ. of Minn.
4479 Webb, L. W., Penn. State College.
4480 Holden, L. L., Worc. Poly. Inst.
4481 Filbert, R. B., Penn. State Coll.
4482 Kneisly, H. L., Ohio State Univ.
4483 Allen, K. R., Worcester Poly Inst.
4484 Roth, E. C., Purdue Univ.
4485 Oehler, A. G., Univ. of Wisc.
4486 Herrman, W. S., Lehigh Univ.
4487 Albing, H. W., Ohio State Univ.
4488 Kinzly, N. T., Ohio State Univ.
4489 Peterman, W. C., Lehigh Univ.
4490 Swope, R. W., Penn State College.
4491 Dyer, W. H., Highland Park Coll.
4492 McAllister, J. D., Highland Park Coll.
4493 Miller, L. G., Highland Park Coll.
4494 Clark, A. B., Univ. of Michigan.
4495 Stearns, H. R., Univ. of Michigan.
4496 Cox, M. L., Ohio State University.
4497 Young, M. W., Ohio State Univ.
4498 Gundel, E. W., Penn. State Coll.
4499 Moore, W. G., Lewis Institute.
4500 Hrubes, J. A., Lewis Institute.
4501 Jilek, F. J., Lewis Institute.
4502 Mixer, A. L., Worcester Poly. Inst.
4503 Dalquest, N. W., Washington State Coll.
4504 Enger, T. K., Univ. of Illinois.
4505 Smith, D. L., Univ. of Illinois.
4506 Foltz, L. S., Univ. of Illinois.
4507 Capek, L. V., Univ. of Illinois.
4508 Conwell, E. M., Univ. of Pittsburg
4509 King, G. A., Worcester Poly. Inst.
4510 Healey, E. A., Harvard University
4512 Reid, J. B., Highland Park Coll.
4513 Ogle, G. W., Highland Park Coll.
4514 Howe, H. W., Univ. of Illinois.
4515 Boreman, R. W., Ohio State Univ.
4516 Cogswell, F. R., Carnegie Tech. Schools.
4517 Blade, E. H., Mass. Inst. of Tech.

Total. 75.

Award of the John Scott Medal

The John Scott Medal was recently awarded by the City of Philadelphia to Mr. D. McFarlan Moore, of Newark, N. J., for his vacuum tube electric light. The award was made upon the recommendation of the Franklin Institure of Pennsylvania, who investigated the Moore Vacuum Tube Electric Light. The medal received by Mr. Moore is circular in form, four inches in diameter and three eighths of an inch thick. The legend engraved upon it reads:

THE JOHN SCOTT MEDAL
TO THE MOST DESERVING
TO
D. McFARLAN MOORE
OF NEWARK, N. J.
FOR HIS
VACUUM TUBE ELECTRIC LIGHT
ON THE RECOMMENDATION
OF THE FRANKLIN INSTITUTE
1910

On the obverse side is placed the seal of Philadelphia with the inscription, "Awarded by the City of Philadelphia." The certificate accompanying the medal reads as follows:

The City of Philadelphia, trustee under the will of John Scott of Edinburgh, through its Board of Directors of City Trusts and on recommendation of the Franklin Institute for the promotion of the Mechanic Arts has awarded the John Scott Legacy Medal and premium to D. McFarlan Moore of Newark, N. J., for his Vacuum Tube Electric Light in accordance with the report of the Institute's Committee on Science and the Arts. No. 2481—Adopted November 2, 1910.

The certificate is signed by the Board of Directors of the City Trusts and by President Walton Clark and Secretary Robert B. Owens of the Franklin Institute.

Digitized by Google

San Francisco Meeting and Japan Excursion of Mining Engineers

A cordial invitation is extended to all members of the American Institute of Electrical Engineers to participate in the 101st Meeting of the American Institute of Mining Engineers, which will be held in San Francisco beginning Thursday, October 10, 1911. It is proposed to secure for the party making the trip West a special *train de luxe*, which will leave Chicago on Saturday, September 30, 1911, at 8 p.m. A day or two each will be spent at the Grand Canyon of the Colorado in Arizona, Los Angeles, Santa Barbara and Del Monte. The party will reach San Francisco on Tuesday morning, October 10. In addition to the usual sessions for the reading and discussion of technical papers, the local committee in San Francisco contemplates a number of excursions in and about the city, including the oil fields, gold dredges, Mt. Tamalpais, Lick Observatory, University of California and Stanford University.

A similar invitation is extended to Institute members to participate in a special excursion to Japan. Accommodations have been secured on the steamships Manchuria and Siberia. The party will leave San Francisco on October 17, arriving in Yokohama on November 3. It is planned to spend 18 days in Japan, leaving Yokohama on November 21, arriving in San Francisco on December 7, Chicago on December 11, 1911. The excursion in Japan will include trips to the Tokio, Nikko and Chuzenji district, Kiota, Nara, Osaka, Kobe, Ikuno, silver mine, Imperial Steel works, etc.

The complete itinerary giving full details including rates may be obtained on application to Dr. Joseph Struthers, Secretary, American Institute of Mining Engineers, 29 West 39th Street, New York City. Members desiring to participate in either of these trips should communicate with Dr. Struthers at once.

Personal

MR. H. E. MURPHY has left the Allis-Chalmers Company and entered the employ of the Stone and Webster Engineering Corporation as construction engineer.

MR. ERNEST R. FELLOWS, formerly in the testing department of the General Electric Company, Schenectady, is now electrical expert aid in the office of the naval constructor, U. S. N., at the Schenectady works.

MR. EDWARD CLAUDE BROWN, until recently with the Public Service Corporation of New Jersey, has been appointed assistant to the superintendent of power stations, Boston Elevated Railway Company.

MR. G. S. ALBANESE, constructing engineer, of Paris, France, has been elected managing director of the Compagnie Francaise des Freins Ackley, 62 Rue St. Lazare, Paris, which company he founded with Mr. G. S. Ackley, inventor of the Ackley adjustable air brake.

MR. ASHLEY P. PECK, until recently sales engineer for the New York office of Allis-Chalmers Company, is now identified with Messrs. A. L. Ide and Sons, and Terry Steam Turbine Company, and has opened a sales office at Room 814 People's Gas Building, Chicago, Ill.

MR. C. F. BEAMES has resigned the management of the power companies controlled by the Northern Ontario Light and Power Company, Ltd., Cobalt, Ont., to accept the position of chief electrical engineer to the government, State of Mysore, India. Mr. Beames left New York for India on August 16.

MR. GEORGE B. SCHLEY has resigned his position as assistant attorney in the electrical patent department of Allis-Chalmers Company, Milwaukee, Wis., to become associated with Arthur M.

Digitized by Google

Hood, 805 Indiana Pythian Building, Indianapolis, Ind., in the practice of patent, trade-mark, and copyright law.

MR. GANO DUNN, who for some years has been first vice-president, chief engineer and a director of the Crocker-Wheeler Company, has resigned from that company to accept an important engineering and executive position. Mr. Dunn sailed for Europe August 26 to attend, as president of the American Institute of Electrical Engineers, the meeting during the Turin Exposition of the International Electrotechnical Commission to be held on September 7, 8 and 9, 1911, and also the following meeting of the International Electrical Congress.

Obituary

WILLIAM DUNLAP SARGENT, of 51 Remsen Street, Brooklyn, N. Y., died on Thursday, August 10, 1911, at his country home in Somerset, Pa. Mr. Sargent was born in Ligonier, Westmoreland County, Pa., on July 2, 1845. He was educated in the public schools of Harrisburg, Pa. In 1861 he entered the service of the Pennsylvania Railroad Company as telegraph operator. Later he served in the United States Military Telegraph Corps at General Burnside's Cincinnati headquarters, and when the war was over he went back to Harrisburg and became manager of the Western Union office there. He was in charge of the telegraph service at the Centennial Exposition in Philadelphia and was present when Alexander Graham Bell exhibited his first telephone there. Mr. Sargent then became interested in the telephone and entered the business with Thomas E. Cornish of the Bell Telephone Company, of Philadelphia, as general superintendent and general manager. Later he went to Brooklyn and became vice-president and general manager of the New York and New Jersey Telephone Company, and while there was chosen to take charge of its exhibit at the Paris Exhibition in 1889. In 1885 he developed, in connection with John A. Barrett, the dry core paper cable in a continuous lead covering, the cable which is now in standard use in the telephone business. He was very active, also, in the long-distance work of the telephone officials of early days, and is recognized as one of the first and ablest of the pioneers in the telephone field. Mr. Sargent was a director of the National City Bank of Brooklyn and of the Brooklyn Public Library. He was a Member of the American Institute of Electrical Engineers, the Brooklyn Institute, the Pennsylvania Society, the New England Society and the Long Island Historical Society. The remains were taken to Fresh Pond, Long Island, and cremated. Mr. Sargent is survived by a widow and three children.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Bliss Electrical School. Catalog, 1911. Washington. 1911. (Gift of Bliss Electrical School.)

Boston Society of Civil Engineers. Constitution and By-Laws and List of Members. June 1911. Boston, 1911. (Gift.)

Brooklyn Public Library. Annual Report of the Board of Trustees. 13th, 1910. New York, 1911. (Gift of Brooklyn Public Library.)

Congreso Cientifico (1° Pan-Americano) Ciencias Economicas y Sociales. Tomo II. Santiago de Chile, 1911. (Gift of Congreso Cientifico 1° Pan Americano.)

Milwaukee Bureau of Economy and Efficiency. Bulletin No. 5. Milwaukee, 1911. (Gift of Milwaukee Bureau of Economy and Efficiency)

Monthly Official Railway List. July, 1911. (Gift of R. W. Pope.)

New York State Advisory Board of Consulting Engineers Report to the Governor. 1910. Albany, 1911. (Gift of Advisory Board of Consulting Engineers.)

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL. DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **ACTING SECRETARY.**

GEORGE A. HAMILTON. FREDERICK L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shal[1] constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH WAINWRIGHT POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

HORACE FIELD PARSHALL,
Salisbury House, London Wall, E. C., London.

L.A. HERDT, McGill University, Montreal, Que.

WILLIAM G. T. GOODMAN,
Adelaide, South Australia.

ROBERT JULIAN SCOTT,
Christ Church, New Zealand.

HENRY GRAFTIO, St. Petersburg, Russia.

Digitized by Google

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
FREDERICK L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
ALEXANDER S. LANGSDORF, St. Louis, Mo.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
FRED S. HUNTING, Fort Wayne, Ind.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman,
165 Broadway, New York.
EDWIN BRITTON KATTE, New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
GEORGE GIBBS, New York.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

ALEXANDER S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
JOHN PRICE JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill.
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman,
General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman,
Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio.
ROBERT BELDEN TREAT, Ampere, N. J.
F. TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman,
15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York.

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman,
43 Exchange Place, New York.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.
PHILIP TORCHIO, New York.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman,
600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

PUBLIC POLICY COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
HAROLD W. BUCK, New York.
JOHN J. CARTY, New York.
JOHN H. FINNEY, Washington, D. C.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman,
2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES WATERMAN STONE, New York.
CALVERT TOWNLEY, New York.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman,
29 West 39th St., New York.
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman,
52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President,
90 West St., New York.
ARTHUR E. KENNELLY, Secretary,
Harvard University, Cambridge, Mass.
Other members of this committee to be appointed later.

CODE OF ETHICS COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.
FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J

Term expires July 31, 1915.
ELIHU THOMSON, Chairman,
Swampscott, Mas
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.
PHILIP PRICE BARTON, Niagara Falls, N. Y
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913.
COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y

Term expires July 31, 1912.
WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.
LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, New York.

Term expires July 31, 1912.
PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.
GANO DUNN, President, Ampere, N. J.
FREDERICK L. HUTCHINSON, Acting Sec.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York. LEWIS BUCKLEY STILLWELL, New York.
LOUIS A. FERGUSON, Chicago, Ill. DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill. CALVERT TOWNLEY, New York.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, Pittsburgh, Pa. SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	H. P. Wood.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor. Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	F. A Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, Wagner Electric Mfg. Co., St. Louis, Mo.
Toledo.....June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto.....Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana.....Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas.....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland.....Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College.....Feb. 11, '10	D. E. Byerley.	A. A. Catlin, Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oregon State Agr. Col Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

Digitized by Google

DISCUSSION ON "COMMENTS ON FIXED COSTS IN INDUSTRIAL POWER PLANTS", AND "THE COST OF INDUSTRIAL POWER", NEW YORK, MARCH 10, 1911. (SEE PROCEEDINGS FOR MARCH, 1911.)

(Subject to final revision for the Transactions.)

Percival Robert Moses: The paper presented by Mr. Parker purports to be a discussion of the cost of power generation and certain features in connection therewith in small plants of the industrial type. Such plants are usually understood to mean manufacturing establishments, but the tabular data presented apply to department stores and have nothing whatever to do with industrial plants as usually understood. I shall discuss this tabular data later.

Taking up the paper in detail, reference is first made to the marginal principle. This principle, as I understand it, is the principle enunciated by Wellington in his theory of street railway location, *i.e.*, that no expenditure is justifiable unless in itself it will earn a fair return. The author states in the following paragraph that since the installation of a plant, costing $10,000 to $20,000, would constitute a physical improvement to the property, it is obvious that the tax assessment will be increased thereby. Practical experience points the other way. I have never had the taxes increased on any building or manufacturing establishment because of the installation of a small private plant; nor, on the other hand, do I know of any decrease in taxation resulting from the shutting down of such a plant.

Regarding insurance, he also discusses the question of insurance and, later on, allows 3 per cent for taxes and insurance. I have already discussed the question of taxation, and the question of insurance is usually one of small moment. The rate in modern fire-proof buildings rarely exceeds one-quarter of one per cent on 80 per cent of the actual value. This is for fire insurance. If to this be added the liability insurance, the total additional insurance due to the operation of a private plant will, even theoretically, not exceed one per cent of the cost of the plant. I say "even theoretically", because unless a plant is quite large, *i.e.*, around $30,000 or $40,000 in value—the amount of insurance on the building is rarely changed. As for the liability insurance, it will usually be found that the labor increase in an industrial plant, due to the installation of a small private generating plant, is inconsiderable and, as the liability premium is figured as a percentage of the pay roll, the *addition* to the liability insurance premium which is the only part that should be charged to power generation is usually nominal. Of course, the matter should be considered, but it should be considered practically and the actual cost allowed not an imaginary cost.

This expense for liability and fire insurance, the author states, is existing whether such insurance is actually carried or not. The fact is lost sight of that the presence of an electric plant, with its additional employees, is an additional safeguard against

Digitized by Google

fire, and if we begin to allow for theoretical additions to insurance we should also allow for theoretical increase in efficiency of fire protection.

The author's discussion of the depreciation of a plant seems entirely fair, except that I believe that in an industrial plant, where the plant is liable to increase in size or to change its character, the depreciation rate should cover the possible obsolescence of the machinery. This is a matter which must be determined in each case by the possibilities of the case.

The author's discussion of the supervision of a plant does not seem to me to be well based. He discusses the possible proportion of the time of a manager which may be taken up in connection with the power plant, then allows for the possible value of this man to the concern and the possible profit that might be obtained from the use of this man's whole time if he were not distracted by the power plant. He forgets to allow for the increased efficiency of the manager due to his increased knowledge of power generation, and that the manager through his connection with the operation of a power plant may learn something that may enable him to double the output of his business. I am treating the matter sarcastically because if we go into possibilities, or, as they were called in the Alabama Arbitration, indirect claims, we will never get at the facts. I believe that it is proper to charge against the plant operation the actual cost of such time as is required for supervision *of the power plant required for the generation of electricity*; *i.e.*, the additional time of the manager that is required to supervise the operation of the electric generating plant—not the time required for supervising the operation of the boilers or deciding questions in connection with the power transmission or with the motors or with the air compressors, but solely the time required in connection with the electric generating plant. If this time is analyzed, it will be found to amount to a few hours during a year —not a few hours a week. And even this amount of time is partly balanced by the services rendered by the operators of the electric generating plant in other parts of the works.

After allowing for interest on the investment and depreciation and possible obsolescence, and taxes and insurance which do not exist in most cases, and for a very large proportion of the time of the superintendent at $10,000 a year the author of the paper proceeds to add a fair profit based on the average profit in the store.

If this paper were an argument in favor of central station service and not an unbiassed investigation of the cost of industrial power, such a proposal might be understood. On the same theory, the rent of the building should be charged at the average profit obtained by selling merchandise—not at what the money could be borrowed for. And, in fact, the merchant could figure that he had no profit at all, because if he had to pay the averaged profit ratio as interest on all the money he borrowed from the

Digitized by Google

bank, there would be no profit. On the author's theory, therefore, we would have clearly proved that the manufacturer or business man had no business to be in business at all.

The recognized and standard method is to charge interest on the investment at the rate at which money could be borrowed, and this interest on the cost of the electric plant is just the same as the interest on the cost of a building or the interest on the cost of an elevator machine; it is part of the rental paid and has nothing whatever to do with the ratio of profit on the sale of merchandise.

The next item in the discussion is the building space and real estate. This is a matter that must be considered in each case. In some cases it is true that the space taken up by the electric plant is valuable and a fair rental value must be assessed against this space. In fact, it may be stated that in all large plants this is the case. But in small plants, of which the paper treats, the reverse is true; and it is the exception rather than the rule that the space taken up by the private plant is space which may be used for other purposes. It is usually space required because of allowance for other machinery, and because of the objection on the part of the builder to place himself entirely in the hands of an outside company.

Appendix A is an interesting discussion of the marginal principle, but like most general discussions its application to special cases requires careful consideration, and Appendix B is a mathematical discussion of amortization or depreciation, as it is usually called. It is interesting to note that the author uses six per cent in this mathematical discussion, whereas on the fair profit theory it would seem more correct to allow the average ratio of profit.

Appendix B, which is the part of the paper that would most appeal to the ordinary business man, contains tabulated statements of figures "presented to and endorsed by the owner and manager of a large mercantile establishment." The figures may have been endorsed by a business man, but they are certainly not correct insofar as standard practice is concerned. The plant consists of a 100- and a 50-kw. unit. The cost of the engines, dynamos and switchboard is placed as approximately $9,000. The engines are high-speed engines. The actual cost of a 100- and a 50-kw. unit, delivered and erected on foundations ready for steam and electric connections, could not exceed $6,000 and I have recently purchased similar equipments for $5,500, as compared with approximately $9,000 given by the author. Similarly, boilers for 150-kw. units should not cost $6,200. Of course, if boilers were to be installed to take care of every thing else in the building besides the electric equipment they might, but the cost assignable to the power plant is certainly not correctly stated at $6,200.

The total given by the author is $20,265 for a 100 and a 50-kw. machine erected and connected, with the necessary boilers

Digitized by Google

and stack. I presume that this is all in addition to the heating equipment cost and boilers required for other purposes. This is at least 50 per cent too high a cost. Not over two weeks ago, orders were placed for two 100-kw. direct connected, high-speed engines, with the necessary additional boiler capacity required for their operation, smoke breeching, steam fitting, wiring, switchboard, at a total cost of $13,000 including engineering charge.

Table 2 shows marginal interest 6 per cent, amortization 2.63 per cent, taxes and insurance 3 per cent, and fair profit ratio (this is in addition to interest) 11.5 per cent, or a total of 23.13 per cent. In my opinion if we allow 6 per cent interest, depreciation 2.63 per cent or even 5 per cent would be more safe, and taxes and insurance 1 per cent we have a total of 12 per cent on a correct installation cost of not over $12,000, or $1,440 per year for fixed charges, as compared with over $4,441 allowed by the author.

I have gone into details in this matter, as this shows how a little added to this item and a little added to that item, and a percentage charged here and a percentage charged there, each so small in itself, may entirely change the facts.

The same thing is true of the gas engine plant next cited, a small plant of 120 h.p., using producer gas produced from 4.5 lb. of coal per kw. hr. Our records from several such plants, operating under poor conditions, show less than 2.5 lb. of coal per kw. hr. A plant recently installed at Stanley G. Flagg & Company's works, Pottstown, Pennsylvania, a 175-kw. plant, ran for a month under regular working conditions with no allowance extra for banking; *i.e.*, the actual coal used for all purposes, was 2.05 lb. per kw. hr., less than one-half that allowed by the author, and this was No. 1 buckwheat coal.

The amount of coal and the cost of labor allowed seem about correct in Table 3, except I do not see why it is necessary to have a night engineer all the year around, whereas when the plant is only used for heating the fireman is only kept at night for 20 weeks. It is evidently not for generating electricity, because an allowance is made for emergency service.

The main discrepancies come under the head of Fixed Charge, which is estimated at $4,441, whereas correctly, as has been stated, this should not exceed $1,440, a difference of $3,000. $1,000 a year is allowed for the manager's time at $12,000 a year rate, it being assumed that the manager will lose this amount of time in connection with the power plant, which he would otherwise use, and that this time will be solely devoted to the electric generating end of the plant as distinct from the rest of the heating plant and power plant.

The space value is stated at $1.00 per sq. ft. This is space—not boiler space—in addition to that required for boilers and other machinery in the basement. The usual rate for basement space is from 10 cts. to 25 cts. per sq. ft. and, in some rare cases,

Digitized by Google

40c. per sq. ft., particularly for space in the middle of a store basement.

Altogether, there seems to be about $4,200 charged against the plant operation which should not be so charged, making the actual cost of the power plant operation $8,763 as compared to over $10,000 with the central station service. It should be noted that the table only allows $25.00 a year for the manager's time, including clerical expense, with the central station service, whereas $1,150 is allowed with the private plant, and the only addition in the machinery line has been the self-oiling engines and dynamos and their connections.

In the gas engine plant, Table 4, 25 per cent is charged for fixed charges, as compared to 12 per cent. The coal per kw. hr. is stated at 4.6 lb., whereas the usual ratio for producer gas engines is a little over 2.25 lb., and this includes coal used for banking. No provision is evidently made for re-circulation of the water, and the allowance 27.2 gal. per kw. hr., is greatly excessive.

One thousand dollars a year is allowed for this little bit of a plant for manager's services. An engineer is charged for extra, presumably in addition to the man operating the heating plant. For a plant of this size, one man should be able to do both, and usually does.

Altogether, the figures presented do not seem to represent even fair average practice, and the allowances for fixed charges and manager's time cannot, in my opinion be defended upon any reasonable ground.

In general the paper is an argument for central station service, and is not an investigation of the cost of industrial power.

David B. Rushmore: Industrial plants are rather sharply divided into separate classes. In the large cities one finds many small industrial plants of a few hundred horse power each, some directly connected to a central station. There also exist other plants of this nature which demand many thousands of horse power, where the desirability of connection to a central station is not so apparent. The cost of industrial power is measured by the manufacturer not at the switchboard but at the point of utilization. In manufactured articles there is a wide variation as to the ratio which the cost of the power bears to the cost of the finished product. In many cases this ratio is not large, which points out the fact that frequently the correct application of the power is of more importance than the cost of it. By the proper design of the power plant, of the electrical system to be used, of the particular motors and controllers, etc., the product in quantity and quality can often be favorably affected to a very considerable degree.

The cost of power is made up of many items, of which the fuel cost is but one and sometimes a minor one. The interest charges, the cost of operation and the maintenance and repair items in many cases, even where a blast furnace or coke oven gas is used, make it preferable to use steam turbines instead of gas engines.

Digitized by Google

Electrical power derived from transmission systems, connected to hydroelectric stations, is being more and more used for industrial power purposes. Continuity of operation is a factor of prime importance in manufacturing establishments, and the reliability of these systems is a consideration of the first magnitude. Transmission systems are in operation which have practically no interruptions, although there are, of course, exceptions. In connection with power taken from transmission systems, the use of a steam turbine reserve, which can be thrown on the distributing system quickly, is in some cases necessary and in many cases desirable. It is not in general appreciated how quickly steam turbines may be started, synchronized and loaded. The time from the first indication of trouble on the transmission line to the condition where the turbo generators are fully loaded on the system need not be over 30 sec., starting all the machines and auxiliaries from rest. The condition of interrupted power supply is being rapidly removed.

R. P. Bolton: I think we are all under a considerable debt of gratitude, whether interested in one form of the use of power or the other, to the authors of these papers. They have some sound and fundamental facts and so far as my judgment and experience goes they are right in their general conclusions. I must controvert the statements of a previous speaker in so far as they refer to insurance on labor, on the hazardous class of which rates have now risen until they amount to nearly six per cent, in addition, to fire and boiler insurance, which thus form a not inconsiderable item of expenditure.

The question of depreciation is very often misunderstood. Depreciation is the result of the failure of maintenance, of upkeep, of repairs, and of all the other attentions that are given to machinery to effect their full purpose of prolonging its useful and economic existence. There are two kinds of depreciation, that which comes about from what is commonly known as physical decay or obsolescence, and that which is due to economic causes. I congratulate myself that my mind has been in this matter working along the same lines as Mr. Parker's, although we have been separated by the length of the State of New York from each other.

As regards the provision for depreciation, I find in Mr. Parker's paper that he has amortized depreciation at a rate of compound interest of six per cent. A preceding speaker took exception to the rate of six per cent interest upon the money invested in a plant of machinery but he did not take exception to the use of a six per cent rate on the amortization, because that had the effect of reducing the amount required for depreciation. In table on page 480, the rate of amortization capitalized at three per cent, which is the rate you can get in most savings banks should average $4\frac{1}{2}$ per cent on the total, and therefore the total in Table 2 should be increased about two per cent.

In Mr. Hibner's paper the load factor which has been as-

Digitized by Google

sumed seems to be too high. In Table 2 on the basis of a working period of 2280 hours per year, it is 86 per cent. By Fig. 3, the actual factor is nearer 40 per cent and the cost would therefore be at least 3.5 cents per kw. hr. This reference leads to consideration of the manner in which uninformed people plunge into the establishment of power plants without knowing anything at all about the subject of load factors. In a recent case where a factory was running on a public service having a very light load and a considerable variation in the power load due to the use of elevators, the owner insisted on putting in a power plant which is so proportioned as to operate on a sixteen per cent load factor.

The use of exhausted steam, as a by-product from plants in commercial buildings, is subject to climatic conditions—the nearer you get to the North Pole the more use may be made of exhaust steam as a by-product; the nearer you are to the Equator, the less use can be made of it. Under such conditions electric demand and heat requirement do not fit together.

The percentages of the sales of live steam supplied by a public steam supply company in this city during the heating months are as follows. October, 3.2; November 7.2; December 15.5; January 25.7; February 22.6; March 20.6; April 5.2. The percentage of steam generated during the same months by a generating plant in a business building near the steam plant is as follows: October 13.4; November 12.9; December 14.8; January 15.0; February 13.9; March 16.1; April 13.73. There are other limitations of the availability and use of exhaust steam, and one which affects the question more than anything else is the load factor. In the operation of a certain generating plant in this city, I found that a kw-hr. is generated for about 6.5 lb. of coal per kw-hr. under the best conditions only for a very limited period of the day. On Sunday the consumption rises to 36 lb. of coal per kw-hr. The generators in that plant are never loaded in excess of 75 per cent of their capacity. Many operating engineers appear to be afraid to operate a unit at full capacity. I recently saw a fine 4-valve engine driving a 250 kw. unit, in a first-class hotel, the load of which at the time was approximately 90 per cent of full capacity, and as soon as that load was reached another generator of equal size was put in operation, reducing the load factor to 45 per cent. I am not against the installation of power plants where they are required, but I am against the introduction of power plants where they are not necessary, and where they are not properly and economically needed is often the place in which they are installed. The kind of engineering I hope to see developed will be that which will refuse to be tied to either side of this question, but will be willing to see the economic side of this very important matter.

Arthur Williams: It seems to me this is a question simply of kw.-hr. cost, so far as the electrical service is concerned, and of the cheapest method of obtaining it. In regard to the first two

Digitized by Google

papers, bearing upon the cost of operating private plants, I am compelled to take issue with the distinguished authors—they have not placed the cost of current, at least under conditions existing in such a city as New York, at anywhere near its true value. In Mr. Hibner's paper, Table I, we have the cost of steam, and, while the details upon which my conclusions are based will be given in my notes to be published in the PROCEEDINGS, I will say that the amount allowed for heating the building with an average heating load of 62 h.p. is altogether too high. By a process of elimination—first, the correction of the investment, lowering it to $2,000, instead of $4,000, we get nearer to the facts. On this basis the annual "fixed charge" on an investment of $4,000 should be $600, but upon the more nearly correct investment estimate of $2,000 it is only $300. As to coal for heating alone the cost appears overstated. Four hundred tons (for an average of 62 boiler h.p. for the heating season) would be sufficient, which at $3.00 would cost $1200. And in the matter of labor, a fireman's wages for a full year have been charged; assuming, as here, that one would be sufficient, his wages for 30 instead of 52 weeks would be $450. Making these changes, the yearly cost of heating the building in question is about $2,000 instead of $2,705. The point may be small, the saving of $705, but it is referred to later when the cost of operating the private plant is considered. Following the same table, we find, first, rather too small an allowance. Mr. Martin admirably covered that subject. My own criticism summarized fixed charges at 15 per cent, and, making this allowance, the final result, which is shown in detail in my own comments, becomes 5.5 cents per kw-hr., instead of 2.29 cents; that is to say, under the conditions existing in New York, and using the same basis that the author used in his paper, we get the larger average cost.

In table III, we come to the question of the producer gas plant. Apparently the author uses a single unit, compounding the interest on the investment, but at a very low rate, altogether too low for that purpose. He allows simply a single engine for a very important building evidently forgetting that producer gas plants are hardly more reliable in their operation and hardly longer in life than an automobile engine, instead of a steam engine. I have changed the ratio of depreciation on the total investment to 20 per cent, giving the reasons, and in this case we again reach a total cost of 5 cents a kw-hr., instead of about 2.5 cents.

Referring to Mr. Parker's paper he again, estimates 2.63 per cent as the annual depreciation, but I do not know of any case—and I have asked several engineers if they knew of any case—where annual depreciation is actually put aside in a fund upon which interest is accumulated from year to year, and the universal answer is "No." Therefore, in my own criticism, I have taken a general depreciation rate of 7.5 per cent. Mr.

Digitized by Google

Bolton has given two causes for depreciation, obsolescence and physical life. There is a third, and that is, the moment that a competing service becomes available at a cost not exceeding the cost of operating the private plant, then the depreciation of that plant has become complete, 100 per cent, and so long, therefore, as its operation is continued, it must be apparent that operation is continued at a loss to the operator. I think, therefore, that I have not gone beyond the bounds of conservatism in taking 7.5 per cent throughout my notes, as the basis of depreciation. Finally, in going through Table I of Mr. Parker's paper—I trust he will pardon me for criticising it in detail—we find that the total cost becomes, by a process of elimination, $8,000 for operating the plant, which is 7 cents a kw-hr.

I heartily accord in Mr. Bolton's suggestion, and I am seriously of the opinion that it is a matter of very great importance to this Institute, that we should have consulting engineers who have no interest whatsoever in the outcome of their advice; that they should be called in to advise the owner as to the cost of power, taking everything into consideration, without reference, finally, to the outcome. Under the present system very largely the engineer must prepare plans and specifications, which are absolutely necessary in most cases to determine the cost and the best way of obtaining power, and if the plant is not installed, that entire expenditure of time and money is lost to the engineer. I think that this, at least in this City, is a very general practice, and in my opinion it is a wrong practice and should be changed. I have ventured to offer some suggestions on this point, which will appear in the PROCEEDINGS.

Finally in summarizing what charges should be allowed, I have taken six per cent as the allowable rate on money, on the theory, at least, that that is as little as any one would expect to get on his investment for any investment corresponding to a private plant.

Now, a word about operating costs. I think there are three points of view—that of the consulting engineer, oftentimes, that of the central station representative, and finally the exact operating cost of the plant after it has been in service some years. I have here simply one point to which I want to draw your attention—some years ago Mr. Isaac D. Parsons presented a paper in the Engineering Magazine, the February 1902, issue, in which he gave the average number of pounds of coal consumed per kw-hr., in a large number of plants. I believe there were three apartment houses, three hotels and three clubs, representing in these three classes the most difficult service in the world with which a central station in a large city must compete. I have never seen the accuracy of Mr. Parson's figures questioned, but I have seen them confirmed in many ways, of which Mr. Bolton has just given an instance. He finds they go as high as 25 lb. of coal per kw-hr. generated, including the coal required for heating. The final of the averages is 17.3 lb., and

Digitized by Google

the average of all, divided by the kw-hr. required, is 15.5 lb. of coal per kw. hr. I think customarily we find in preliminary estimates from 6 to 7 lb. allowed.

In conclusion, let me give you three exact illustrations of the cost of operating private plants in this City. The details are given in my notes, and will be found of interest, because they represent very careful tests which have cost several thousand dollars. The first is a modern office building of 3,000,000 cu. ft. The admitted cost last year, from the books kept by the owners, of light and power, heat, and the elevator service, was $36,085. This is an exact statement. Central station service has been offered, under any guarantee which the owners may require, including the heating of the building, for $27,000 a year; that is, the entire element of fixed cost, which in this case becomes $9,000, may be ignored, and the central station service, plus the cost of heating the building from the boilers on the premises, is identical with the present cost of operating the plant. The second case is a modern hospital, the expenses of which admittedly ran to $24,580, with nothing allowed on the original investment of about $60,000. The authorities of the hospital have been offered a contract under which the total cost of heating, plus the cost of electric current supplied from the street, cannot exceed $22,000 a year. My third illustration, which is the most difficult of all with which to compete, is a large modern hotel—the costs here were taken from the books. The investigation was made by two engineers of note in our city, one jointly employed, and the other employed only by the owners of the hotel. The cost in this case is $41,297. 500,000 kw-hr. were made, and this item of $41,297 includes nothing but fuel, labor, removal of ashes, some repairs, etc., but nothing for interest, depreciation, taxes or insurance. They were made an offer of $40,920 as the cost of steam heating supplied from the building and electricity purchased from the street. There again the entire element of fixed charges may be waived, and yet the two costs balance each other. I think the figures given in my analysis will be found typical upon correspondingly careful investigation of the conditions that exist in practice in large buildings in such a city as New York.

Parker H. Kemble: I think all of us who have occasion to look up the costs of a private plant service, as compared with a public corporation service, should be grateful to the authors of the paper this evening for emphasizing a lot of points that are not usually clearly brought out. The points to which I wish particularly to call attention are in Mr. Hibner's paper, especially Table III. The item of profit is given at five per cent. I do not think any manufacturer will go into business on the basis of a five per cent profit, with the anxiety and worry and chance of failure, when that profit can be obtained by the purchase of any ordinary good bond on the market. I called up a half dozen manufacturers in Brooklyn and asked them what turn over they

Digitized by Google

would consider it necessary to have on $15,000, in order to make it worth while to take it up and consider it. The lowest man of the six gave a turn over of 15 per cent, on the basis of five per cent for the use of the money, giving a net profit of ten per cent, or twice the amount given in the paper. The highest man of the lot gave a turn over of 30 per cent, stating that they turned over their money on an average of ten times a year, with a profit of three per cent each time. Between these two extremes, I should say it would be safe to take 15 per cent as a matter of profit. If this is added in to the cost of power, it will bring the cost up to a little over two and three-quarter cents.

Another point, as to the amount of coal—my experience in plants of this size has shown that in the neighborhood of ten pounds of coal is a conservative figure. If that is taken into consideration with the profit matter, it will bring the cost per kw-hr. to 2.84 cents. If any expense is allowed for the time of the manager which he spends in looking after the plant, that of itself will bring the cost, irrespective of the other item, up in the neighborhood of 2.5 or 2.6. Any two of these three items added together will bring the cost of power, based on Mr. Hibner's figures, to over three cents. Any large public service corporation will be very glad to supply power to a plant such as outlined here, with a load factor as given here, for 3 cents per kw-hr. on a term contract, which is the point I want to bring out.

H. H. Edgerton: I have for the last year been paying particular attention to the cost of electric current as generated in private plants.

I have here the data as to costs in one case, that may be considered fairly typical in regard to equipment and results for equal output. The plant is of 460 kw. generator capacity:

Total engine and boiler room expenses: 1909–10	$39,894.00
Total expenses for electric service	12 809.61
Credit for exhaust steam used in heating	3,157.28
Net cost of 461,600 kw-hr.	9,652.33
Net cost per kw-hr.	2.091 cents
Interest and depreciation, $4,600	0.997 "
Total per kw-hr.	3.088 "

The electric service included lighting, ventilating motors and vacuum cleaning service; also 28.4 per cent of the heating and hot water service.

The elevator service, six elevators, pumping service, ice machine, sewage evacuators and remainder of the heating and hot water services was from other than electric power sources.

The cost of fuel (pea coal) was $4.20 per ton. The division of the fuel and labor accounts was based upon a series of engine indicator cards, taken over the period of a year.

I notice that in Mr. Parker's paper that central plant current is estimated, selling price, at about 3 cents per kw-hr. In this locality that figure would not cover interest and depreciation, let alone production and distribution costs.

Digitized by Google

C. M. Ripley: If by any chance these proceedings of this evening should find their way into the hands of industrial men, and others who have the decision in their hands as to whether they shall make or buy their electricity for their new plant, I would like to have this go on record—that the Commonwealth Edison Company of Chicago of my own certain knowledge own and operate three isolated plants in the basement of buildings. If industrial plant owners, managers and engineers need any further encouragement regarding the earnings of an isolated electric plant I will say that the Commonwealth Edison Company is glad to pocket the income from such, even after paying a fancy rental for the basement space occupied. Some of these plants are equipped with Corliss engines and others with high speed engines; the owners of industrial plants can likewise depend on and profit by similar apparatus designed by the same manufacturers.

H. W. Peck: At the present time, with men designated as engineers in the foreground of nearly every large economic analysis, more papers of the general character of the one presented by Mr. Parker to-night should be given before the engineering societies. Aside from the subject of railroading, there have been very few such papers—too few. We should have in our TRANSACTIONS, for example, an analysis of the principles of depreciation corresponding to Dr. Alexander Humphrey's classic before the American Gas Institute. I regard Mr. Parker's paper as a valuable contribution to our proceedings, outlining, briefly and clearly, the principles appertaining to a certain detail of everyday engineering work. Mr. Hibner's paper is valuable, also, as it discusses a subject which is of great moment to a large number of engineers; and while in most of the individual cases industrial plants are relatively of small importance, the sum total of them amounts to an exceedingly great figure, and the amount of engineering work being expended on them is very great.

Referring to Mr. Parker's paper, certain parts might properly, it seems to me, have been elaborated a little more. Other methods of providing for amortization can properly be mentioned, as, for instance:

1. A yearly sum equal to the investment, divided by the number of years' expected life, should be set aside annually, allowing the variable earnings of this fund to be added to the other earnings of the company.

2. A variable yearly sum, equal to a fixed per cent of the decreasing back value of the plant, may be set aside; for example, 10 per cent of the full value at the end of the first year, 10 per cent of the remaining value at the end of the second, year and so on. This method would never completely amortize the plant, but would more nearly represent its actual depreciation in value, and leave a relatively small amount to be charged off in one sum at the end of its natural life, or, indeed, somewhat earlier.

My own preference is in favor of the first method, although

Digitized by Google

the choice of methods may very reasonably differ for different classes of business and different financial conditions.

Inadequacy should properly be mentioned with obsolescence, as in general the same considerations hold good for both conditions. Similarly, *business risk* is an element of *fair profit*, though not always associated in one's mind.

In certain points I do not agree with Mr. Parker. I would call attention to the fact that the depreciation rate on certain details, considered by themselves, is not correct when they are considered as part of a plant; for example, a building which might be in excellent condition after 50 years, would, in all probability, not be useful that length of time, nor for a period any longer than the life of the equipment in it. I have in mind an expensive brick chimney and engine room which was discarded in four years' time to make way for a larger one required by increase in the business requirements. In this case the matter of inadequacy would have required a 25 per cent depreciation rate instead of a 2 per cent, which might have been allowed from the consideration that the building would be in fair state of preservation for 50 years. Of course, if this condition had been anticipated, a chimney and engine room of larger capacity would have been installed originally, so that I am not arguing for an amortization rate of 25 per cent, but simply wish to mention one of a number of illustrations of the fact that inadequacy is very likely to be the consideration which will determine the proper sinking fund.

I emphatically disagree with Mr. Parker's statement that "obsolescence, therefore, has essentially no existence for private power plants, even under stress of competition." If I purchase a plant to furnish power to operate my factory, finance it on a 20-year basis, and in five years' time improved equipment can be purchased with double the efficiency of my apparatus, a new competitor will be able to undersell me by an annual amount equal to one-half the power cost. I then have to choose between the loss of one-half the power cost annually, or the unamortized part of my plant, less its sale value. This seems to me very clearly to be the case, in fact, Mr. Parker practically admits it in a following paragraph.

The sale value of the old plant should, of course, be added to the sinking fund and be credited to the new equipment.

The charge of $2,000 for supervision is proper, of course, regardless of the salary actually paid for supervision, unless here again the marginal principle applies in apportioning the time of the superintendent, that is, that a sacrifice of 20 per cent of his time would not sacrifice 20 per cent of the profit of the business.

Under the subject *Fair profit*, it should be noted that items of necessity do not have to carry their own burden of profit; for example, an ordinary business cannot be carried on without artificial heat in the winter. The total cost of heating must be

Digitized by Google

carried by the profit-making parts of the business, assuming that heat cannot be purchased from a heating company. Thus the various elements making up the cost of heat must be deducted from the corresponding elements making up the cost of combined heat and power before figuring the actual cost of the power alone. This is illustrated well in Mr. Hibner's paper except, possibly, for the considerations following.

I have observed that if 100 tons of coal per month are required for heating a building, and if 100 tons are required for power alone, it is assumed that 100 tons, or possibly 110 tons, to allow for loss in the engine, will be sufficient for both heat and power. Where the requirements so nearly balance this is manifestly not the case, for the heating requirements are distributed throughout the 24 hr. of the day, with a marked peak early in the morning before the business part of the plant begins operation. The power requirements, however, are limited to from 8 to 10 hr. a day, with the peak usually during the warmer parts of the day, or during the late afternoon, just before shutting down the factory, when it is permissible to allow the temperature to drop slightly. This means that the coal for combined heat and power may easily amount to from 150 to 175 per cent of the coal required for either purpose alone.

I do not like Mr. Hibner's use of the expression " load factor " with the limitation of ten hours. I think it is very generally agreed that load factor should be limited to daily, monthly, or annual load factor.

John H. Norris: The following examples of installations of gas engine costs of operation are presented to show the economy that can be obtained even down to small sizes when using the gas engine for power purposes. I have selected a few typical plants running on various fuels. Owing to the fact that the cost for buildings or rent for space varies so much, I have not included in my costs hereafter given any allowance for said buildings or space occupied by the installations.

Plant No. 1 is a 50-h.p. 3-cylinder gas engine direct-connected to a 125-volt direct current generator with a speed of 275 rev. per min. running on natural gas and furnishing an 11-hr. service 300 days per year.

The load on this plant is 15 kw.

Cost installed	$3,500.00
Interest and depreciation	$350.00
Repairs and supplies	175.00
Labor per year	900.00
Total operating cost, exclusive of fuel	$1425.00
Gas bill for year	315.56
Total yearly charge	$1740.56
Total kw-hr. for year	49,500
Cost per kw-hr	3½ cents.

Plant No. 2 is a 25-h.p. engine belted to a 15-kw. generator and one 20-h.p. engine belted to a 12-kw. generator running on natural

Digitized by Google

gas and furnishing light and power running at approximately full load; service 16 hr. per day 365 days per year.

Cost installed, $4,200.

Interest and depreciation	$420.00
Repairs and supplies	210.00
Labor per year	700.00
Total operating cost, exclusive of fuel	$1330.00
Gas bill for year	1270.18
Total yearly charge	$2600.18
Total kw-hr. for year	128,480
Cost per kw-hr.	2.02 cents.

Plant No. 3 consists of one 65 and one 30-h.p. gas engine furnishing power for a manufacturing establishment running on illuminating gas at 80 cents per 1,000 ft.

Cost installed, $4,375.

Interest and depreciation	$437.50
Repairs and supplies	220.00
Labor per year	360.00
Total operating cost, exclusive of fuel	$1017.50
Gas bill for year (80c. gas)	3279.00
Total yearly charge	$4296.50
Total h.p. hr. for year	228,000
Cost per h.p. hr.	1.89 cents.

Plant No. 4 consists of one 100-kw. and one 65-kw. direct-current sets, operated by gas engines running on city gas at 65 cents per 1,000 ft. 11-hr. service.

Cost installed, $12,300.

Interest and depreciation	$1230.00	
Supplies and repairs	600.00	
Labor per year	2000.00	$3830.00
Cost of fuel per kw-hr.	1.6	
Operating charges	0.7	
	2.3 cents per kw-hr.	

Plant No. 5 consists of two 75-kw. and two 65-kw. direct-current generating sets operated by gas engines and running on city gas at 65 cents per 1,000 cu. ft.

Cost installed, $23,000.

Interest and depreciation	$2300.00	
Supplies and repairs	1150.00	
Labor per year	3300.00	$6750.00
Fuel cost per kw-hr.	1.6	
Operating charges	0.3	
	1.9 cent per kw-hr.	

Plant No. 6 consists of one 40-h.p. and two 18-kw. gasoline engines direct current sets furnishing light and power to a country estate.

Digitized by Google

Cost installed, $9,580.

Interest and depreciation	$958.00	
Supplies and repairs	480.00	
Labor per year	1500.00	$2938.00
Cost of fuel per kw-hr.	2.025	
Operating charges	1.29	
	3.315 cents per kw-hr.	

Plant No. 7 consists of one 15-kw. gasoline engine direct-current set used for lighting service in connection with storage batteries.

Cost installed, $2,500.

Interest and depreciation	$250.00	
Supplies and repairs	140.00	
Labor per year	400.00	$790.00
Cost of fuel per kw-hr.	2.025	
Operating charges	1.78	
	3.805 cents per kw-hr.	

Plant No. 8 consists of a 35-h.p. anthracite producer, 28-h.p., 2-cylinder vertical gas engine, 24-hr. service.

Belted to an 18-kw. generator.

Furnishing light and power.

Average load, 10 kw.

Fuel, anthracite pea coal at $4 per ton.

Cost installed, $3,000.

Interest and depreciation	$300.00	
Supplies and repairs	150.00	
Labor per year	500.00	$950.00
Cost of fuel per kw.at 4.00 per net ton	0.3	
Operating charges	0.61	
	0.91 cents per kw-hr.	

Plant No. 9 consists of one 300-h.p. anthracite producer, suction type, furnishing gas for two 100-kw. Allis-Chalmers generators of 60-cycle three-phase, 2300 volts, running in parallel and operated by two vertical gas engines. Fuel, pea anthracite at $4.00 per ton, 24-hour service.

Cost installed, $22,000.

Interest and depreciation	$2200.00	
Supplies and repairs	1100.00	
Labor per year	2400.00	$5700.00
Cost of fuel per kw-hr.	0.3	
Operating charges	0.4	
	0.7 cent per kw-hr.	

Plant No. 10 consists of one 400-h.p. double-acting tandem horizontal engine running on producer gas furnished by two 200-h.p. anthracite suction producers driving flour mill by rope drive and grinding a barrel of flour for 8 lb. of coal

Digitized by Google

Fuel, used No. 1 buckwheat coal.
24-hour service.
Cost installed, $38,000.

Interest and depreciation	$3800.00	
Supplies and repairs	1900.00	
Labor per year	3000.00	$8700.00
Fuel cost at 7.00 per ton	0.42	
Operating charges	0.3	
	0.72	cent per b.h.p.-hr.

Plant No. 11 consists of 400-h.p. double-acting tandem horizontal engine direct current 2,200-ton ammonia compressor.

Twenty-four-hr. service and giving 30 tons of refrigeration per net ton of coal, coal being Illinois slack, carrying 38 per cent volatile matter and averaging 10,300 B.t.u. per lb.

Cost installed, $44,000.00.

Interest and depreciation	$4000.00	
Supplies and repairs	2000.00	
Labor per year	4500.00	$10,500.00
Cost of fuel (coal) per h.p	0.1	
Operating charges	0.361	
	0.461	cent per b.h.p.

Plant No. 12 consists of a 300-h.p. anthracite suction producer driving a four-cylinder vertical engine direct connected to a 200-kw. direct-current generator furnishing power and light.

Cost installed, $18,000.

Interest and depreciation	$1800.00	
Supplies and repairs	900.00	
Labor per year	1500.00	$4200.00

Fuel used, No. 1 buckwheat; cost per ton, $4.00 delivered.

Cost of fuel per kw-hr	0.3	
Operating charges	0.63	
	0.93	cent per kw-hr.

I have a record of a three weeks' run on this plant, in which the following figures may be of interest:

Total kw-hr. furnished	19,368
Elapsed time	480 hours
Per cent running time	36 per cent
Per cent shut down time	64 per cent
Average kw	113.85
Per cent of full load	56.9
Coal per kw-hr., including all standby losses	2.36 lb.

I have also a record of a run of one week in which the average kilowatts were 87.28.

Per cent of full load	43.6
Coal per kw-hr	3.46 lb.
Per cent of time running	37.2 per cent
Per cent of time shut down	62.8 per cent

In these two runs there has been no attempt to meet test conditions. There are simply the reading of the instruments

Digitized by Google

and the actual amount of coal supplied to the producer during the time specified.

Plant No. 13 consists of a 150-h.p. anthracite suction producer, furnishing fuel to a 150-h.p. three-cyclinder vertical engine direct connected to a 100-kw. direct-current generator furnishing power and light to a manufacturing establishment. Eleven-hr. service. Fuel, pea anthracite at $4.00 per ton.

Cost installed, $9600

Interest and depreciation	$960.00	
Supplies and repairs	480.00	
Labor per year	750.00	$2190.00
Cost of fuel per kw-hr.	0.3	
Operating charges	0.66	
	0.96 cent per kw-hr.	

Plant No. 14 consists of three 200-h.p. producers, furnishing fuel to one 600-h.p. double-acting tandem gas engine direct connected to 400-kw. alternating current generator, 60-cycle, three-phase 600-volt, furnishing power for cement mill.

Fuel, Texas lignite, carrying 8000 B.t.u. per lb. and costing $1.50 per net ton delivered. 24-hr. service.

Cost installed, $40,000.

Interest and depreciation	$4000.00	
Supplies and repairs	2000.00	
Labor per year	3200.00	$9200.00
Cost of fuel per kw-hr.	0.169	
Operating charges	0.32	
	0.489 cent per kw-hr.	

Plant No. 15 consists of one 150-h.p. suction producer furnishing fuel to one 150-h.p. vertical three-cylinder gas engine direct connected to a 100-kw. generator furnishing light and power.

Cost installed, $9600.

Interest and depreciation	$960.00	
Supplies and repairs	480.00	
Labor per year	1700.00	$3140.00
Cost of fuel per kw-hr.	0.17	
Cost of operating	0.4	
	0.60 cent per kw-hr.	

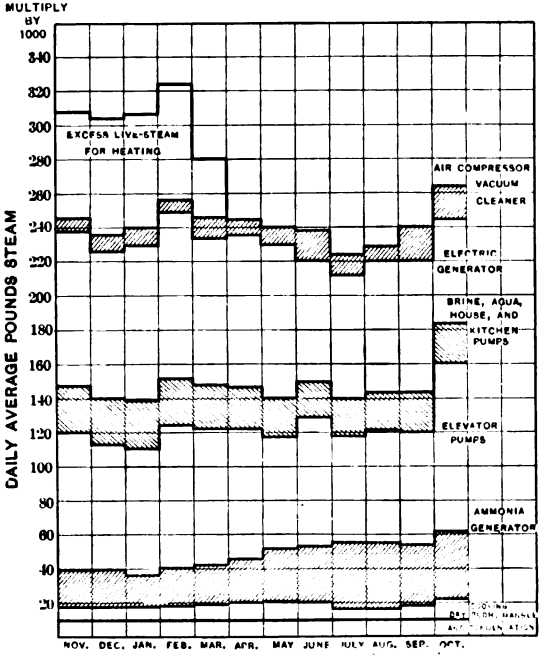
In connection with this plant, I have a record of a 38 days' run which is as follows:

Duration of run	912 hr.
Time shut down	75 hr.
Per cent time running	91.75 per cent
Per cent time shut down	8.25 per cent
Total kw-hrs.	38,353
Total lignite supplied to producer	196,520 lb.
Consumption per kw-hr.	5.12
Cost of fuel per kw-hr.	0.42 cent
Operating charges, as above	0.43 cent
Cost per kw-hr. at 40 per cent load	0.85 cent

Digitized by Google

Referring to the statement of Mr. Williams, that the gas producer is a very unreliable piece of apparatus, I would like to state that as a matter of fact the depreciation of a gas producer properly run is less than that of a steam boiler plant, and the gas producer of to-day is a very satisfactory and reliable power generator.

Richard H. Tillman: The paper by Mr. Parker on "Fixed Costs" will more than likely bring out sufficient discussion to have its title more appropriately termed "Variable Fixed Costs". Notwithstanding this fact, however, the paper repre-



CURVE NO. 1.—Showing operating conditions. Typical hotel plant Steam distribution

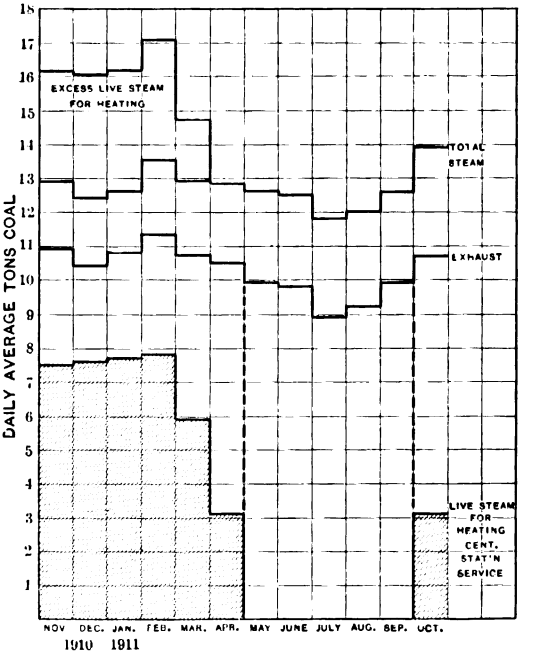
sents the cold facts so plainly that it will be hard to refute the claims made therein. This paper will be the means of bringing out many ideas and will be the base of much good work in industrial engineering.

One item of fixed costs entering into an industrial power plant which has not been brought out plainly in the paper is what we might term "first interest and depreciation costs". When a new factory is to be located the first large expense is made in the power plant equipment. This equipment is usually purchased to supply the total needs of the complete industry

Digitized by Google

and sometimes, contemplated additions to the factory. It is usually several months from the time the power equipment is purchased before any factory is operated at its full capacity. It is evident that the greater part of the fixed costs begins when the plant is first purchased.

The amount of fixed costs that can be charged against plants in an unfinished condition will, of course, depend on the size and type of construction and machinery used, or the time that portion of the plant is idle. In the case of purchased power, where the power rates are based upon the fixed costs on the actual


DAILY AVERAGE TONS COAL
EXCESS LIVE STEAM FOR HEATING
TOTAL STEAM
EXHAUST
LIVE STEAM FOR HEATING CENT. STAT'N SERVICE
NOV DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEP. OCT.
1910 1911

CURVE NO. 2.—Showing operating conditions. Typical hotel plant Coal consumption

power demand metered, the first fixed costs on a new industry will not be so heavy.

In the paper entitled "The cost of Industrial Power" by Mr. Hibner, we find some very interesting as well as valuable points. Most of the figures presented in this paper can certainly be verified by figures from different locations. There is one question which I would like to ask concerning Table II of the paper.

Under the head line "Operating Costs of Power Plants" there are two items, namely "Banking" and "Night heating".

Digitized by Google

I would like to ask Mr. Hibner what is the difference between these two items, and how are they arrived at.

As mentioned in Mr. Hibner's paper, we find that the actual industrial power plant costs are very indefinite. Also estimates on the necessary capacity for industrial plants have been found to more than double the actual requirements when the plant was put in operation. I have known of instances where the consumption in kilowatt hours of an industrial establishment was estimated by considering the total rating capacity of the boilers for the total time the factory was operated. To demonstrate this let us consider one of the many industries in which Baltimore leads—the manufacturer of fertilizer. The actual costs which we have found to exist in three factories for the past twelve months are as follows:

	"A"	"B"	"C"
Connected load	198 h.p.	170 h.p.	350 h.p.
Maximum demand	75 kw.	91.5 kw.	92.5 kw.
Av. monthly consumption	14410 kw-hr.	19118 kw-hr.	10592 kw-hr.
Load factor (10 hr. 26 days)	74 per cent	80.4 per cent	44 per cent
Motor capacities	1–50 h.p.; 1–40 h.p.; 1–30 h.p.; 3–20 h.p.; 1–15 h.p.; 1–3 h.p.;	1–100 h.p. 3–20 h.p. 1–10 h.p.	5–40 h.p.; 1–35 h.p.; 1–20 h.p.; 2–15 h.p.; 5–10 h.p.; 2–7½ h.p.
Approximate output in tons per month	3500	6000	3500

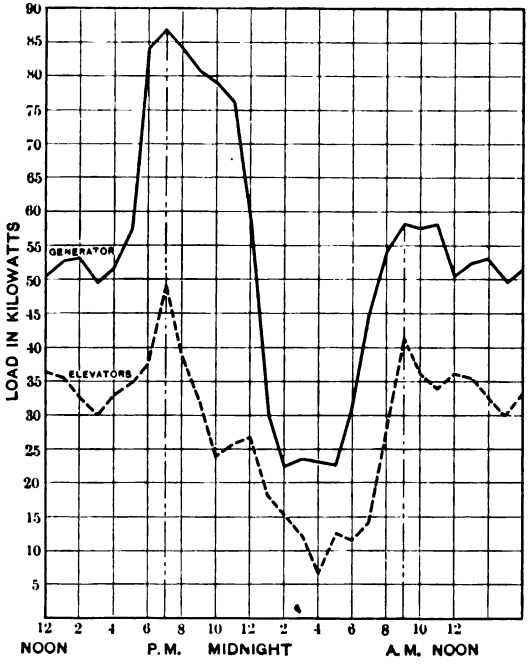
The plant estimated for the column marked "A" included one 200-kw. unit and one 100-kw. unit and a consumption of 35,000 kw-hr. per month. This tabulation shows a high load factor on "A" and "B" factories, and this is caused by the fact that part of the machines are operated 22 hr. per day, while those in factory "C" are operated only 10 hr. per day.

In comparing the labor requirements in these factories with the tabulation given in the papers, I might state that in no one of them is any expert labor required to attend the electrical equipment. An oiler passes through the factory about twice during the day and takes note of the bearings, spending the remainder of the time at other work.

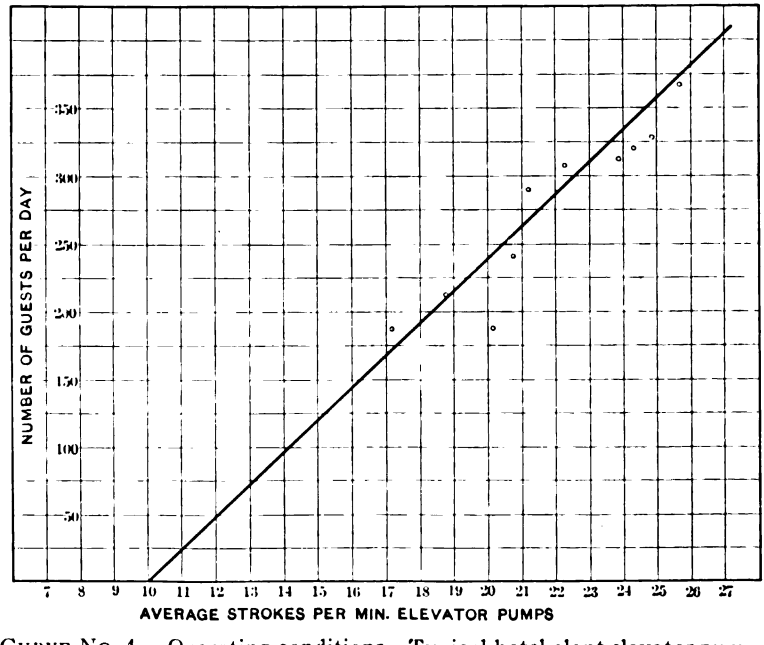
There has but lately come to my notice a forceful instance of how a plant may be over burdened with fixed as well as operating costs, by a biased engineer. I have prepared curves to illustrate how this could have been easily obviated by careful investigation and comparison of plants of similar type; also how the costs entering into the total expense of a plant can be separated.

This plant consists of 525 kw. in generating units and the maximum electrical demand is 90 kw. It is not necessary to comment on the fixed costs of such a plant. By the use of a

Digitized by Google



CURVE No. 3.—Load showing operating conditions Typical hotel plant



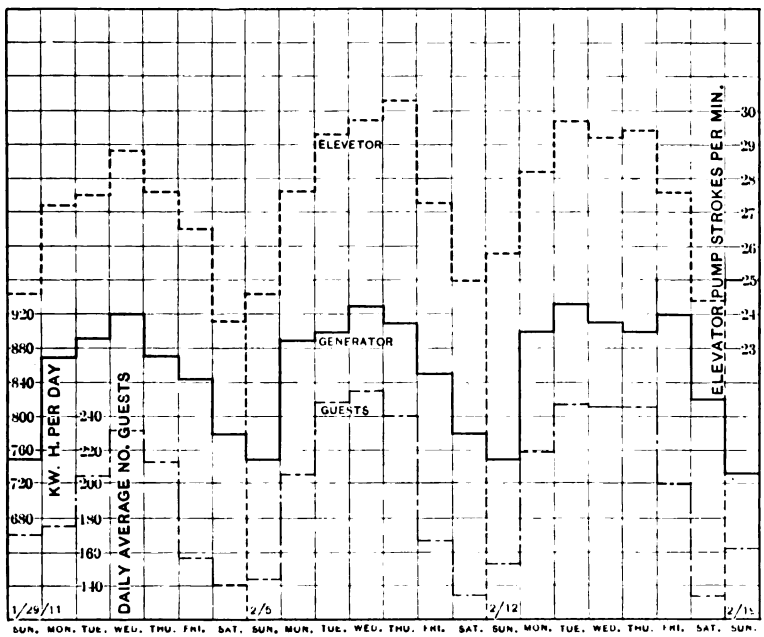
CURVE No. 4.—Operating conditions. Typical hotel plant elevator pumps

Digitized by Google

condensing apparatus the steam for various services was determined.

The steam distribution is figured on the basis of 8½ lb. steam per lb. of coal, and Curve 1 shows graphically the exact amount of coal used for the various services in the Hotel plant. This far south heating is carried on from about the middle of October until the middle of April, and includes only about 150 days for heating per year.

Curve 2 shows steam represented in terms of equivalent coal value. Total exhaust is also shown, and the difference between



CURVE NO. 5.—Operating conditions. Typical hotel plant Generator and elevators

total steam and exhaust gives the live steam used for cooking, mangles, ice machine, etc. The shaded portion represents full value of live steam to replace present exhaust as used in heating.

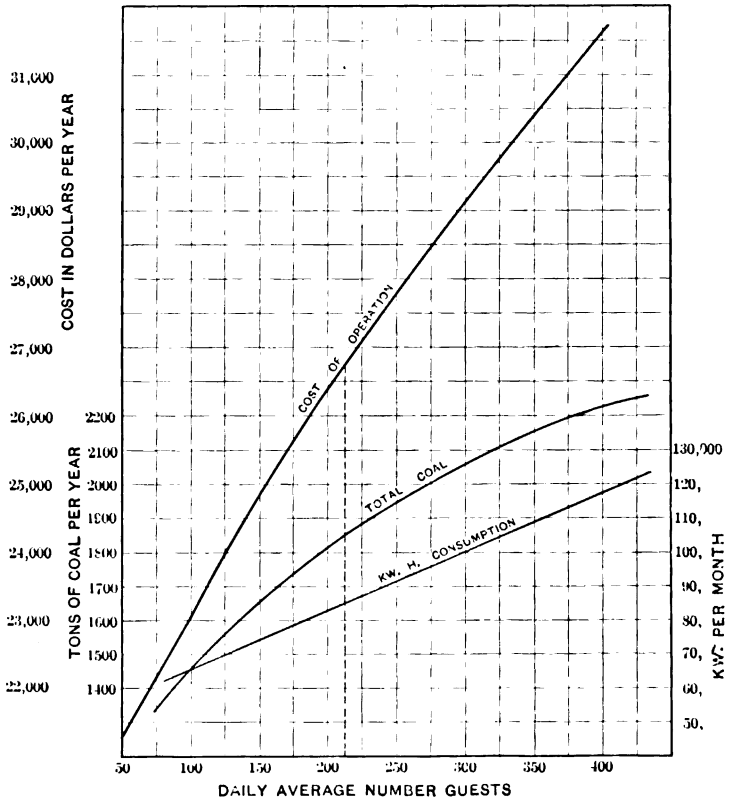
Curve 3 shows the load curves of the Hotel plant in operation. It will be noticed that the peaks on elevator pumps varies practically with the peak on the generator. The various power requirements of the hotel holds the load up during the day as shown.

Curve 4. In various hotel plants tested it was found that the power requirements varied with the number of guests. If observations are taken over a considerable period of time, curves

Digitized by Google

can be plotted which establish the working law by which the power requirements for any given month can be calculated when the total average number of guests is known. It is to be noted that when the number of guests is reduced to zero that the pumps are still doing work. This is due to the help, freight elevator, etc.

Curve 5. This curve shows how closely the operation of the



CURVE NO. 6.—Cost of operation, central station service
Typical hotel plant

generator and elevator pump depend upon the number of guests. This is a typical business man's hotel. The falling off in the number of guests at the end of the week is characteristic of this type of hotel.

Curve 6. This curve shows the cost of operation. This factor bears a certain relation to the total average number of guests. It is to be noted that the greater the number of guests

Digitized by Google

the less the variation in cost for a given increase in number, showing that a high load factor for guests is also a profitable thing for a hotel.

W. S. Timmis: The power plant installed at 435 East 24th St. consists of three 250-h.p. water tube boilers, two 150-kw. direct-connected generators with compound engines, one-100-kw. generator, compound engine, and one 50-kw. direct-connected generator, simple engine. Also two $7\frac{1}{2}$-kw. balancer sets.

The cost of this outfit is given as follows:

Boilers, including setting.		
3 250 h.p. water tube	$11190.00	
Engines.		
2 150-kw. compound		
1 100-kw. compound		
1 50-kw. simple	12190.00	
Generators	6100.00	
Balanced draft	2325.00	
Steam Fitting.		
Includes all auxiliaries	6378.00	
Total cost of plant		$38,183.00
Cost per kw		84.85

This plant has been in operation for over three years. It was installed to accommodate a much larger load than it has been called upon to carry; with a capacity of 450 kw., the average load, taking a period of one year, has been 127 kw.

The following table gives the actual cost of running the plant for a period of one year from January 1, 1910 to January 1, 1911.

Wages (cost to run one year)	$5233.84
Coal	4817.69
Water	360.00
Ashes (removed)	223.24
Oil and waste	164.40
Supplies (packing, sheet rubber, pump valves, soda-ash, boiler handhole gaskets, piping, etc.)	159.27
Repairs	263.28
Total	$11221.72
Interest and depreciation on cost of plant $38,183 at 12 per cent	4581.96
	$15803.68

Kw. metered 381,500.
Cost per kw. $0.0294 without interest and depreciation.
Cost per kw. $0.0412 including interest and depreciation.

During the year there were 722 hr. overtime at time-and-half per hr.:

Assistant engineer	75c. per hr.
Fireman	56c. per hr.
Sundays and holidays (5 days and 6 hr.), which makes a total of	$1021.32*

*This item is included in the total amount under wages.

Digitized by Google

The above figures include the cost of heating the building, the value of which is estimated as follows:

Coal 585 tons	$1949.75
Two firemen 30 weeks, $15 each	900.00
Part time of chief engineer	500.00
Water	30.00
Removal of ashes	90.00
Interest and depreciation on boilers 250 h.p. and distributing panels, $4740.00 at 12 per cent	568.00
Total	$4037.75

Deduct from the total cost of running power plant for one year, $15,803.68.

The amount for heating, $4,037.75.

Cost of running power plant less value of heating, $11,765.93.

Actual cost of current, 0.0323.

The cost of Edison service at wholesale rates for the amount of current generated would have been, $17,660.16 as against cost to operate plant, including all charges $11,765.93. Leaving balance in favor of plant, $5,904.23.

At the time the plant was installed it was thought that a much larger load would obtain.

Stonewall Tompkins: The power plant of the Coney Island & Brooklyn R.R. Co., is not one of the large ones, but may, for this reason, be not less interesting for discussion.

Description of Plant

The power house is located at Ninth Street and Gowanus Canal, Brooklyn. Coal is delivered in lighters from which it is hoisted into storage tanks which discharge by gravity into a car which runs into the boiler room. The coal used is a mixture of No. 3 buckwheat and bituminous, the latter constituting about one-eighth of the entire mixture. Stoking is done by hand. Air pressure under the grates is supplied by steam-driven blowers, the speed of which may be regulated. The burnt gases discharge into a 200-ft. stack, and a nearly balanced draft is maintained by hand controlled dampers. Shaking grates (the back half of which may be dumped) are used under water tube boilers. Feed water comes from the city mains, and is heated in an open heater by the exhaust from blower engines, pumps, etc. The main generators are vertical shaft turbine-driven alternators, and the exciters are horizontal turbine-driven. The turbines exhaust into barometric condensers, having motor-driven centrifugal pumps, and steam-driven flywheel dry vacuum pumps. There are steam-driven pumps for the step bearings, and for the oil-pressure governors of the turbines. The plant operates twenty-four hr. per day every day in the year. There are two daily peaks in the load, the greater one occurring about 6:00 p.m. and the lesser about 8:30 a.m. The effect of the seasons is to make the load heavy in hot weather on account of great traffic, also heavy again in cold weather on account of extra current used

Digitized by Google

in heating the cars, and in overcoming bad track conditions of snow, sleet, etc.

Each car of coal is weighed as it enters the boiler room. Water is measured by meter on the city supply, (and the cost of water herein given covers not only all evaporated in boilers, but all other water used about the plant). The electric energy is metered at the switchboard, but a small portion of this is afterwards used to drive the circulating pump motors, and is not separately metered. It has, however, been estimated at 3 per cent of the total output of the plant, and therefore the total output of the power house as herein given is 3 per cent less than the actual metered amount.

LIST OF EQUIPMENT

2 2,000-kw. three-phase turbines.
2 75-kw. exciters.
2 Barometric condensers.
2 Motor-driven centrifugal pumps.
2 Steam-driven dry vacuum pumps.
2 Steam-driven step bearing pumps.
2 Steam-driven pumps for oil pressure governors.
2 Steam-driven blower engines.
2 Steam-driven boiler feed pumps.
6 600-h.p. water tube boilers.
Boiler pressure, 175 lb.
Primary voltage, 11,000 volts.

It should be noted that the expenses for power herein shown do not include the following items:

Interest on investment.
Depreciation.
Taxes.
Insurance.

Nor do they include anything for the pro rata expenses of the officials of the company:

Power House. Total energy (11,000 volts three-phase) measured at power house switchboard, and delivered to cables for transmission to sub-stations.....26,122,312 kw-hr.

POWER HOUSE EXPENSES

Fuel, (41,517 gross tons).....	$81,170.06
Labor.....	51,617.97
Water.....	10,503.53
Lubricants.....	1,724.14
Supplies and expenses.....	4,510.78
Repairs of steam machinery....	9,757.44
Repairs of electric machinery...	2,077.59
	$161,361.51
Cost per kw-hr. alternating current.	$0.006084
Cost of coal per gross ton.....	1.955
Coal per kw-hr.....	3.5662 lb.

Sub-stations. Total energy (575 volts direct current) measured at substation switchboards, and delivered to feeders.....23,065,393 kw-hr.

Digitized by Google

SUBSTATION EXPENSES

Labor	$14,053.56
Supplies and expenses	203.77
Repairs in stations	472.59
Repairs to ducts	874.77
Repairs to 11,000-volt cables	992.04
Total substation expenses	$16,596.73
Add total power house costs	161,361.51
	$177,958.24
Cost per kw-hr. delivered to the direct current feeders	$0.007715

F. G. Gasche (by letter): This paper deals with a subject so timely and important that I feel impelled to urge its widest distribution. The author has made reference to the small plants particularly, but the principles are frequently of general application, and it seems that some of the larger power plants could have been studied to great advantage by methods proposed by Mr. Parker.

The observations concerning "investment" and "interest" cannot be emphasized too strongly, as many additional responsibilities are assumed as soon as a sum of money is appropriated for a given power plant.

The element of "depreciation" is unquestionably subject to variant views, but the evidence of past experience of many engineers would indicate that depreciation "rates" are generally too low and this for a reason quite foreign to the physical permanence of an engine or other part of a power plant equipment. I refer particularly to the rapid changes in method or process which characterize an industry, thus making a power plant obsolete so far as its primary functions are concerned. This may be illustrated more clearly, but I would urge that many industrial power plant elements should not be credited with a useful existence of more than ten years since they may be wholly unsuitable for the purposes of a new business. To illustrate, twenty years ago the simple, vertical, long crosshead type of blowing engine was installed at a group of four blast furnaces. About eight years after, half the group of engines was replaced by larger machines with large steam cylinders, so as to operate them as disconnected compound units. In fifteen years time from the start, they were practically superseded by improved forms of compound engines. About two years ago the new engines were "assisted" by gas driven blowing engines using blast furnace gas, with the implied intention of displacing all steam blowing engines. Now arises the "specter" of the turbine driven turbine blower to set all finance of the power plant "agog" in view of the possibilities. The point I wish to emphasize from this is that fundamental changes in the iron and steel business imposed these changes and not the mere "obsolescence" of the elements of the power plant. Nevertheless, they had a short life. Other lines of industry, not excepting the

Digitized by Google

business of furnishing electric current, have exhibited similar crises in their development.

There is another element of growing importance in the finance of power plant investments which may for the want of a better name, be called " insurance on reliability ". This consists of the aggregate of annual charge that should be set against the gross earnings by virtue of the presence of " spare units ", or duplicate equipment of boilers or other apparatus, the purpose of which is to insure uninterrupted service of the plant for any loads that may be assumed. In some cases a full examination of this " reliability " charge indicates that a mistake can be made in the installation of prime-movers of excessively large capacity.

For many lines of industry there are periods of enforced idleness so far as a part of the power plant is concerned, and it is somewhat surprising to note their influence on the power plant finance since the accumulation of interest and similar charges is continuous.

The ultimate result of the examination of the finance of power plant investments will consist in the statement of a series of numerical items affecting the final numerical values of net returns on the investment. Consequently any consideration involved in such analysis, must be capable of measurement in terms of numerical dollars.

A continuance of the study of the subject as illustrated by the paper of Mr. Parker, will ultimately lead to a consensus of opinion as to the nature of the elements entering the problem, and to a knowledge of the laws controlling their effects as illustrated by the " marginal principle " proposed by Mr. Parker. We may hope for the ultimate development of the algebra of finance calculations as a necessary preliminary to proper numerical substitution. Finally, and most important, the selection of interest rates, amortization rates, and all similar items must be established in accordance with legal and geographical restrictions, to say nothing of the attitude of banking interests whose ruling would be almost a finality.

Bearing on this, there is great danger in applying a greater interest rate to the formulas in appendix B, than banking concerns would allow for such loans bearing interest compounded semi-annually. This would seem to limit the interest to 3 per cent or at the most, to $3\frac{1}{2}$ per cent, corresponding to the usual savings bank allowance. Certainly the amortization period cannot be calculated with the formulas of appendix B, with the legal rates of interest for time loans applied.

William B. Jackson (by letter): There is no doubt that the cost of power as generated by isolated plants is usually underestimated by those having such plants in charge. This is likely to be due to a combination of several causes.

It is usually difficult for the management of a mill or factory to fairly recognize charges that should be made against power

Digitized by Google

generation on account of the work required of the purchasing department of the mill and on account of the proportion of the effective usefulness of the management diverted from the regular business of the company. The former may be of minor importance, but it is likely not to be negligible, while the latter may be of material importance since it diverts the attention of the management from the prime business of the property. An effective management should have sufficient work in developing the business of the company to fully absorb all of its effective strength and resources.

Likewise, it is almost impossible to obtain recognition of extraordinary costs that are incident to an isolated plant, such as those occasioned by uncertainty of coal supply as regards cost, quality and quantity, expense on account of labor strikes, and the uncertainties of the labor market, the occurrence of accidents occasioning extraordinary expense not covered by ordinary forms of insurance, and other like expenses.

If the management costs and the costs occasioned by extraordinary occurrences are fairly taken into account, they are likely to prove a very respectable proportion of the total cost of power generation, and in many instances, I estimate they will be 10 per cent or more of this cost.

I find that the average mill owner who is operating his own power plant, has little definite knowledge of the actual amount of power that he is using. There is the same tendency to overpower a mill when driven by a steam engine as is so noticeable when electric motors are used, and there is an inclination to consider the full rated horse power of the engine as representing the power requirements of the mill. Also, there is usually small appreciation of the comparatively low load factor incident to the operation of most factories or mills, so it is natural that there should be a tendency to over-rate the amount of power being used, and therefore, to under estimate the cost per unit of power.

It is an extraordinary superintendent of a factory steam plant who will seriously combat such misconceptions regarding the cost of the output of his plant, since both pride and policy lead him to accept the lowest plausible figure that can be arrived at as the cost of the output of his department. In many cases, there is honest belief in unreasonably low figures for cost of power. This may be illustrated by a case wherein the management of a mill fully believed they were producing twenty-four hour power for 310 days in a year at less than $20 per indicated h.p. yr., that is, per 7440 h.p.-hr., and they had figures to substantiate this belief. By the results of a carefully organized and conducted test of the plant, with an accompanying complete study of the conditions, they were clearly shown and fully convinced that they must add 50 per cent to the cost they had theretofore accepted as a true one. This was an unusually well-conducted isolated plant operating a large cross-compound condensing engine.

Digitized by Google

A serious difficulty in the way of obtaining a clear conception of the relative costs of industrial power by different isolated plants, is the uncertainty as to what are the relative conditions under which the power plants are operating. If intelligent comparisons are to be made, it is not sufficient to know the cost per h.p-hr., or per h.p-yr. These mean little in themselves except as related to the plant to which they refer, and under particular load conditions. It is impossible to intelligently compare costs or to obtain a true understanding of what the costs for power really mean without having a knowledge of the costs per h.p-hr., subdivided so as to show the costs of fuel, for oil and waste, for repairs, for boiler room labor, for engine room labor, for insurance and taxes, for management expense, for unforeseen contingencies, for depreciation and for interest, and the basis upon which the two latter are determined must be known. In addition to a knowledge of these costs, an understanding of the operating conditions must be had, including the cost and quality of fuel, the cost of water, how many hr. per day the plant runs and how many days in the year, the variations in load during individual days and from day to day, the size of the plant, the ratio of the average load to the maximum load of the plant, and the ratio of the maximum load to the economic full load capacity of the boiler plant and of the engine plant.

With these data, the relative performance of the plants as affected by their construction and operation may be determined.

The above seems a formidable array, but any comparison of plant costs becomes less and less valuable as the subdivisions are omitted, until the point is reached where merely the total cost per h.p-hr., and the size of the engine are known, when the data becomes substantially worthless for comparative purposes. It is thus seen that published costs of power, unless accompanied by very considerable data, cannot be valuable as giving a true understanding of the cost of power. As an illustration of this, had the load factor in the plant heretofore referred to been half as good as it was, the cost per h.p-yr. 7440 hr. would have been 50 per cent greater than it was found to be. This is assuming the same running hours for the plant and the same uniformity of load during individual days.

R. Tschentscher (by letter): The subject discussed by Mr. Parker treats of a matter concerning which there exists considerable misinformation and a material lack of appreciation of the various details. It can truely be said that the proper appreciation of " fixed costs " is decidedly limited among engineers and business men. The paper specifies a reference to industrial power plants but it is very probable that the remarks made and the subject treated apply to all power plants, as it appears to the writer manifestly illogical to assign factors governing a return value on the dollar invested in one plant materially different from those for another plant. In arriving at the cost of power, the same elements are in evidence as exist in arriving at the cost

Digitized by Google

of any other commodity, be this commodity overalls or transportation. The readily determinable operating costs—fuel, upkeep, operating labor, etc.—are too frequently given serious consideration to the exclusion of the consideration of the really more important elements comprising fixed charges. It is frequently factors comprising " fixed costs " which govern the success or failure of an enterprise, be it the generation of power or the handling of transportation. The proper determination of these fixed charges is much more difficult of analysis than that of the operating costs and leads to greater erroneous deductions.

In connection with the matter of " investment " it must be appreciated that the investment charge may vary from year to year, *i.e.*, for example, a 10,000 kw. plant in a certain locality may represent a total investment charge (equipment, land, buildings, engineering, erection, etc.) of $1,000,000. Within five years, the value of land may have increased 25 per cent. Building material and labor may have increased a like amount so that replacement of the building would be increased 25 per cent. Cost of copper, iron and other raw material may have so increased that to reproduce the plant would require an investment of $1,250,000. This, of course, would increase the total amount of taxes, interest, depreciation, etc., which must be considered. The writer believes that the consideration of this feature must be given due weight in the determination of the installation to be made. It is possible that the appreciation of the investment may be such that the fixed charges due to this appreciation may be so great as to offset the gain in operating cost of one installation over that of a less expensive installation.

The definition of depreciation given by Mr. Parker is not as fully appreciated as it should be. The determination of the proper depreciation period is an extremely difficult one and as this item is the largest of those constituting " fixed charges " it deserves the greatest consideration. For example, what is this period for (*a*)—a high grade high pressure steam turbine plant, (*b*)—a blast furnace gas engine plant, each installed during 1910. The depreciation period will depend to a considerable extent on the number of spare units (making investment high but repairs and actual depreciation less) and also upon the operating time of each unit. In other words, the actual depreciation period (considering this period in this connection as the " worn-out period ") will be longer in a plant where the various units are operated on a 10-hour basis than where they are operated on a seven-day-per-week 24-hour basis. The question of the efficiency of the operating labor is also a determining factor of the question of depreciation. A plant may be located where, either because of ignorance on the part of the management or on account of local considerations, the equipment is handled by inefficient operatives. This not only affects operating costs but also the depreciation period. Other factors may enter, all of which indicate that the determination of the proper depreciation period is largely a local one.

Digitized by Google

In an operating plant, the depreciation rate may be suddenly altered due to a material improvement in economy by the addition of other equipment to the existing plant. For example, the non-condensing reciprocating engine (and in many cases the condensing steam engine) has, during the past few years, had its economical life extended by the advent of the low pressure turbine, the combination of the reciprocating engine and the low pressure turbine giving a materially improved overall economy at a comparatively small added investment charge. Low pressure turbines are, in the majority of cases, installed in reciprocating engine power stations so that land and building charges are distributed over a materially increased installation. This same consideration may, in the future, be applied to the depreciation period of a gas engine plant in which, by the installation of low pressure steam turbines operating from boilers which utilize gas engine cooling water and the gas engine exhaust as sources of heat. The writer believes that subsequent events will show this item of depreciation to be in error more frequently than any of the other estimated charges, either fixed or operating and it therefore behooves commercial engineers to give the matter the most comprehensive investigation.

Mr. Parker, in treating of the subject of "supervision" states in effect that the plant should be charged with uneconomical supervision. The usual manager, particularly the manager of an industrial plant, may not have sufficient knowledge to properly handle or supervise the power plant installation. Because of such a limited knowledge, more of his time is required than if especially trained supervision were employed. This specially trained supervision could, in most cases, be obtained at a lower rate than the rate being paid the manager and therefor the supervision charge would be materially decreased. It appears unfair therefore to charge the plant with more than the cost of proper economical supervision other than that of the local manager. The effect of this special supervision will also be to reduce the total investment because of the superior knowledge of the trained supervisor leading to economies of which the local manager would be ignorant. If proper supervision is not employed, then it appears to the writer that an additional item of fixed charge should be incorporated entitled "bad management" as an exhibit for future comparison.

C. A. Graves: The writer would like to emphasize the point brought out by Mr. Hibner regarding the selection of a competent engineer to advise in regard to the power plant installation.

This engineer should not only be familiar with power plant equipment, but also competent to advise in regard to the layout of the machinery, shafting and motors. The industrial manager is interested, primarily, in the power cost of the manufactured product rather than the cost per kw-hr. and, while a power plant may be installed to produce a certain number of kw-hr. at a rate

Digitized by Google

of, say 3 cents, if the proper care had been exercised in installing the motor equipment, a smaller amount of power would have turned out the same amount of manufactured product at a lower cost though the cost per kw-hr., may have been increased to 3½ cents.

Power, whether purchased or generated, should not be wasted, and to prevent waste, attention should be given to the laying out of group or individual motor drive in such a way as to balance the shafting friction against the motor friction or efficiency. Many installations are over motored, and it is also a common error to take the sum of the average motor loads as the average load at the switchboard. The switchboard load, however, is less than this sum, the difference depending on the number of motors and the class of the work; and switchboard watt-hr. meters will register considerably less current than is usually estimated.

Another common mistake is to give as the maximum demand, the sum of the estimated demand for power and the demand for lights, forgetting that the peak load for power in most industries comes about 10 or 11 a.m. and that the load is below the average at the time the lights are turned on around five p.m. These abnormal estimates as to the maximum demand and kw-hr. consumption are favorable to a private plant in most cases.

Now, if in taking up a new proposition the layout of the shafting and motors are considered first, and the question of the purchase or manufacture of power taken up after the machinery has been laid out in the best possible manner, it will be found that central station service in the majority of cases will be best suited for the case. Another point which should be considered is the fact that the price of coal is tending to increase, or the grade to decrease. This means that the cost of power will tend to increase in a private plant. On the other hand, the tendency of central station rates is to lower, because the station load factors are improving; the increased cost of coal having but little effect on the central station's cost of delivering power, because it is so small a part of their total cost of serving their customers; so that within a few years proposed private plants will be generating current at costs higher than it can be purchased. This brings us back again to the amount to allow for obsolescence: and the question should be " How many years will it take before the central station price reaches the cost of generating in the private plant."

It seems to the writer that the central station men think that the consulting engineer will always advise an isolated plant because some plants operate cheaper than the quoted rates, and the consulting engineer believes the central station man wants to get every private plant shut down because some plants operate cheaper on street service.

At the rates quoted by central stations there is a portion of the private plants in their locality which can operate as well or better

Digitized by Google

on the central station service; there is a portion of them which operate at a little lower rate than that quoted; and there is a portion which operate at a considerably lower rate than quoted.

Central stations, as their business grows and the diversity factor increases, are making rates which will secure to them the most profitable business, and many loads which are good for private plants are better for central stations, so that a certain portion of these private plants will be shut down at each reduction of the central station's rate.

Frank F. Fowle: Mr. Parker's paper presents some of the phases of a very live question which is present in nearly every locality where central stations are campaigning vigorously for new business. The issue is the central station versus the isolated plant—not a new problem, but one that promises to remain with us indefinitely and one which constantly reveals new angles.

The owner, or prospective owner, of an isolated plant is the person who most deserves sympathy, for he is beset on one side by the central station man and on the other by the manufacturer of isolated plant equipment, each of whom is determined to have his business, at almost any cost. In the midst of this keen and sometimes bitter competition, it is not to be wondered at that the owner is perplexed over the extravagant and conflicting statements often set forth by each side. This is clearly a situation wherein the disinterested consulting engineer can be of the greatest service to the owner. In many cases the owner avails himself of such service; and again he decides the issue himself, often to his ultimate loss.

The central stations and the manufacturers, recognizing the owners' need of engineering advice, are now generally equipped with sales engineers, or men in an equivalent capacity, whose services are tendered without direct charge. Without denying the expediency of such a plan from the sales standpoint, it is important for the owner to see that such advice comes from partisan sources and he ultimately pays for it, although perhaps not realizing that fact.

Both sides sometimes represent to the owner that he needs no consulting engineer, because their engineers are equally qualified to advise him, with the benefit (apparently) of no expense on his part. Frequently the owner accepts this proposition and relies entirely upon such advice. For his own protection, however, in such a case, he should have the plans and estimates thus prepared submitted to a disinterested engineer for the purpose of checking them and passing on the question of economical operation.

The position of the sales engineer is clearly partisan, for he cannot justify himself to his employer unless he secures business which would not otherwise be secured—and his work thus partakes of a commercial character in a large degree. It is also considered legitimate commercial tactics to so plan the owner's installation, whatever it may be, that he will find it inadvisable

Digitized by Google

or perhaps very difficult to change his policy after it is once adopted.

This implies no fault-finding with existing practices, because every business man is presumed to have sufficient business acumen to protect his own interest, either personally or through those whom he retains. At the same time it is quite proper to point out the results which often attend such practices where the owner is unqualified to pass on the issues and fails to avail himself of advice which is neutral with respect to the competing interests. The owner is the one who must assume the risks and bear the losses, if any there are.

A study of Mr. Parker's paper brings out clearly the importance of considering and weighing carefully every item of cost, under each operating assumption. The matter of depreciation is of course vital, and should no more be over-estimated than under-estimated. The use of the term amortization in the sense of physical depreciation conflicts with usage which has hitherto obtained. The term depreciation implies the shrinkage in value of all physical property, while amortization covers intangible capital, such as franchise cost, organization cost, licenses with a fixed term, etc. In the present case, under the definition just given, amortization would play practically no part.

The method of securing a depreciation fund which Mr. Parker discusses, by the accumulation of a sinking fund from semi-annual increments at compound interest, is not universally accepted as a satisfactory theory of depreciation. An account of some discussion on this subject by the writer will be found on page 796 of the October 6, 1910 issue of the *Electrical World*. The issue here is between the sinking-fund curve and the straight-line theories of depreciation. The difference is not consequential in relation to the average annual assessments to create the reserve fund, but concerns the present value of the plant at any intermediate stage of its life. There is a marked difference between the methods in the last respect, with numerous arguments in favor of the straight-line theory. The latter is considerably the more conservative of the two and it accords most nearly, in the writer's opinion, with the encroachments of true physical depreciation and the corresponding shrinkage of serviceable value. The straight-line method assumes compound interest on the accumulated fund, just as in the other method.

The marginal theory of investment return is important to consider, of course, but Mr. Parker's deductions from it can perhaps be carried further. In general it may be said that the whole investment in an industrial enterprise consists of plant or property, raw material and stock on hand, product in the course of manufacture, finished material and stock on hand, furniture, fixtures, tools, teams, etc., and liquid assets or working capital. The power plant, as a profitable investment, is no different from other property which can be rented. For example, if the average

Digitized by Google

profit from the business is quite high, and an equivalent interest rate be applied in computing the cost of owning, say, a warehouse, it is almost a foregone conclusion that it will be cheaper to rent than to own one. And so on, any property or plant which can be rented will generally be cheaper than ownership under a very high rate for the use of capital—that is, the capital can be used more profitably in the enlargement of the output capacity or the sales organization.

On the other hand, if the rate of return is low comparatively, the ownership of much property and plant may be an economy and the lower the rate, down to the usual return on safe investments, the more plant it will pay to own. But, in the first case the concern's credit will be much better than in the second, under like management, and the needed capital would be attracted, whereas in the last case the capital might be difficult to get—which shows the anomalous results of the marginal theory as thus applied.

Mr. Parker's discussion of the curve in Fig. 1 of his paper is extremely interesting, and the conclusions drawn from that particular curve seem to be sound. But it is quite obvious that the curve may take some other form and thus modify or alter the conclusions. It is also noteworthy that the growth and expansion of an industry is not alone a matter of capital; it is also dependent upon capable management and salesmanship and again upon the existence or creation of a market, with possible competition. Any business or industry which earns 20 per cent net for a long series of years, through successive periods of prosperity and depression, is remarkable and indeed the exception. It is reasonable to suppose that such a business is a protected monopoly or one enjoying quite exceptional advantages. Ultimate competition may conservatively be expected and such a result tends always to depress prices and reduce the profit.

The prime requirements of a growing business may not be so much a matter of capital as one of aggressive salesmanship; and if the net returns are large, it is obvious that the new capital thus created can be returned in part to the business, if needed. The concern which owns a well constructed plant, equipped for economical operation, is the one in the strongest position to weather a period of depression or resist competition. Low production costs admittedly may not be imperative when business is at its height and profits are large; but the inability to attain low costs may be disastrous when conditions change.

It seems to the writer that it is more conservative to assume money at 6 per cent, or even 7 per cent, and compare the economies on this basis, leaving it to the owner to decide where his capital can be used most advantageously. The owner is the final arbiter, in any case; while the function of the engineer is to set the real facts clearly before him. A decision not to install an isolated plant when, for example, the investment will earn 10 per cent, while the industry in question earns 15 per cent, is

Digitized by Google

not fundamentally a question of the comparative economy of the central station service versus the isolated plant, but one which concerns the supply of and demand for capital, and the price at which it can be had, in view of the risks involved.

One more feature of Mr. Parker's results is worth careful study. The results of Table III show quite a saving in favor of central station service. On the isolated plant side there are several items which are perhaps open to discussion. The assumption under emergency service that there will be four days shut-down per month seems excessive; in fact the need of emergency service is open to question, and Mr. Hibner, in the comparison in his paper, assumes none. When the plant units are subdivided there ought to be a very small chance of full shut-down. The allowance of $1,000 for manager's time seems like rather expensive supervision, and it may be noted that no such expense is carried in the other account, which seems hardly fair. Clerical expense at fifty cents per hour is also a rather high item. The rental value of the floor space, at one dollar per foot, may be proper of course, but it is high for many industrial plants. Revising the table and taking fixed charges at 12 per cent, equal to 6 per cent interest, 3 per cent taxes and insurance and 3 per cent depreciation, which are fully ample, it would appear about as follows:

	Central station	Isolated plant
Fuel	$1380	$2290
Ash removal	16	25
Labor	1080	2780
Supplies and repairs	160	366
Water	12	60
Electric service	6259	
Elevator service	415	415
Fixed charges, 12 per cent	384	2304
Supervision	200	500
Clerical expense	25	150
Rental of space		500
	$9931	$9390
Saving		541

This result is in considerable contrast with $2,816 on the opposite side of the balance sheet. The showing in favor of the isolated plant is not marked, but it would probably increase with the growth of the industry and the size of the plant. The owner's decision is not necessarily in favor of the isolated plant, for reasons before given; but a statement in such form is at least

Digitized by Google

conservative and it leaves with the owner the question of deciding where to use his capital or his credit to the best advantage.

In addition to my remarks on Mr. Parker's paper, in relation to the interest rate to be used in computing fixed charges, which apply also to Mr. Hibner's paper, there are a few points of further interest.

He emphasizes clearly the influence of the uses for exhaust steam, which is often the factor that really controls this question. In fact, when the industry uses steam in considerable quantities in manufacturing processes, in addition perhaps to heating, it is very difficult if not impossible to show superior economy for central station service. Power in that case is essentially a very cheap by-product. When there is little or no such use for steam, on the opposite hand, central station service is ordinarily the cheapest by a considerable margin.

In some cases another feature presents itself which has an important bearing on the net economy. This is the possibility of selling exhaust steam or electric energy from an isolated plant to neighboring industries or business concerns, or perhaps to tenants on the same premises. The revenue thus derived must be in excess of the bare operating cost for the service rendered, of course, or it will represent a loss; but it will usually show some profit and diminish the fixed charges. This plan will be most profitable where some diversity in the different demands is present and where the retailed steam or power is not of sufficient quantity to necessitate a very material increase in the size of the isolated plant. The latter cannot ordinarily compete with wholesale rates for electric energy unless the exhaust steam is needed in industrial processes or can be sold; neither can it afford to distribute either steam or power to any great distance. But in a compact district the sale of by-products may show considerable profit.

In comparing tables I and II of the paper it is notable that 5 per cent profit is included in the fixed charge in the second case, but not in the first. As pointed out in connection with Mr. Parker's paper, there is no reason why the power plant, as an investment, should be put in a class by itself and assessed with an interest rate equal to the average net profit on the whole industry. The same rule should be applied in table I to the heating plant, but preferably not to either plant. Applying it to both plants, it is obvious that the higher the interest rate the greater the disadvantage under which the power plant is placed, because it represents a much larger investment than the heating plant.

Taking away in Table I the 5 per cent profit, amounting to $575, leaves the net additional cost of power over heating as $4926 or $0.0205 per kw-hr. This compares very favorably indeed with wholesale rates for electric energy. The central station rate given in table III of Mr. Parker's paper, with slightly larger demand and consumption, is $0.0247 per kw-hr.

Digitized by Google

Taking away the 5 per cent profit reduces the unit cost about 10 per cent.

Similarly, taking away the profit in table III, amounting to $845, reduces the unit cost to $0.0217 per kw-hr., or about 13 per cent. This does not affect the question of comparative economy, however, between steam and producer gas, except in a small amount.

Looking at this whole question in a very broad way, it appears from the standpoint adopted here in the case of the isolated plant that the more profitable the industry the less the economy of production need be considered. On the face of things this may seem true, but in terms of gross costs and volume of net returns it is not true. Prosperity begets extravagance and from a state of great prosperity many propositions can be deduced theoretically which are largely artificial. For the ultimate gain of the community the central station ought to acquire all business which conservative economy justifies it in having; at the same time the acquisition of business which can be handled most economically by an isolated plant, is an economic burden in the end.

H. G. Gille, Thomas M. Gibbes: We have gone over Mr. Parker's paper somewhat in detail and feel that he has covered the subject very thoroughly. There are, however, a few points that cannot be emphasized too strongly.

Our experience is that industrial plant owners rarely if ever consider anything in the form of investment except the engine and generator. We therefore feel that the items enumerated by Mr. Parker should act as a guide for working up the investment of any industrial plant.

The item of insurance is a matter of great importance both in industries where inflammable material forms the part of the industry and also where a life hazard is contracted, such as in department stores and public buildings.

Interest on investment, depreciation and obsolescence are thoroughly covered and need no comment.

Supervision and fair profit are probably two items that are rarely if ever considered in the cost of producing power. A parallel case would be the machine shop, they would not consider for a moment installing a milling machine or a gear cutting machine if the amount of money saved on the product of these machines amounted to only a fair interest on the investment of machinery, as no business could exist if a profit was not earned on top of such interest.

R. Norsa: There is one point in Mr. Parker's paper that I will briefly discuss; that is the straight line formula which has been assumed to represent the *investment* cost in a plant. The author has pointed out that the linear equation $\$ = A + B \times$ h.p. is only roughly true. But, as a matter of fact, we start out with this approximate representation of the investment cost, in order to come to a practical application on the sale of electrical energy;

Digitized by Google

therefore it seems very important to investigate if the above expression is sufficiently rigorous.

Now this question of cost seems to me much more complex than can be represented analytically by a first degree equation, or graphically by the corresponding straight line. Of course no law of cost is susceptible of reduction to a mathematical form. Only in a few cases some theoretical investigations are possible, as *e.g.*, for the prices of some machinery.

Thus for a line of transformers of a given design and type, it may be shown that the weight of active material increases approximately as a certain power n of the rated capacity, and it may be assumed to vary according to the equation

$$\text{weight} = \text{constant} \times (\text{kv.-a.})^n$$

This would be a linear relation if $n = 1$. But if in all transformers of the above line, induction and current density are the same, that is if the losses per unit weight are constant, then n is approximately equal to $\frac{3}{4}$. Consequently the law is not linear but parabolic. As regards the cost, the law will not be very different, and therefore we see that with the increase of capacity, there is a decided saving in weight and consequently a gain in cost. This well known example has been recalled only for the purpose of showing that, even in theory, the straight line formula does not generally hold.

If now we consider the investment in a plant as a whole, the law of the cost becomes very complicated; this law will generally not even be uniform and is not mathematically determinable. We may however admit that a mathematical expression may have some value if it approaches the average conditions, and we may agree that for a plant of a given capacity the *actual* cost may fairly be represented by a fixed expense A and a cost B for each kilowatt. But if we assume A and B as constants and we write

$$\$ = A + B \times \text{kw.}$$

then this equation is supposed to represent the *law of investment cost* in the above plant and consequently it may be applied also to an additional investment, or in other words we assume for each added kilowatt the same cost per unit B, as given by the analysis of the present plant. Now if it is not easy to predict generally what investment will be required by each added kilowatt, we may however state that the cost of the added capacity will very likely be different from the present. If the addition does not require some substantial modification, the added capacity will generally correspond to a lower cost B per unit. Practically we may attempt to follow roughly the law of cost, by saying that the investment is made up of B_1 dollars for each of the first K_1 kilowatts, *plus* B_2 dollars for each of the next K_2

Digitized by Google

kilowatts and so forth, being $B_1 > B_2 > B_3$ . . . . etc. That is, the coefficient B is no more a constant but varies according to a sliding scale depending on the capacity.

We have above been discussing the cost as regards the investment per kilowatt of central station capacity. Now when we come to examine the sale of energy, one of the elements on which we must fix our attention is (as Mr. Parker already pointed out) the value of the service as determined by the cost of securing an equivalent service in some other way, for example by a private plant. As regards the investment costs of isolated plants, we may now repeat exactly the same considerations, and consequently we shall see again that a straight line formula is not suitable to express the investment costs of these plants; but we shall find as before that the cost B per kilowatt decreases with the increase of the capacity.

On the other hand it is also well known, that with increasing demand of a consumers plant, the cost to the central station of having the service ready at his premises generally increases *with decreasing rapidity.*

The foregoing remarks have been confined to the investment cost and the conclusion may be expressed very briefly. Mr. Parker has very clearly shown the opportunity of a gradation of the B charges on account of the seasonal diversity depending on the seasonal demand of different consumers and also on account of the daily diversity depending on the daily demand at the time of the peak. But as the coefficient B is not a constant, a still further gradation of the B charges, according to greater or smaller demands, should also be considered.

Discussion at Boston, March 22, 1911

Henry D. Jackson: I have read Mr. Parker's paper with a good deal of interest, and in this connection one point strikes me particularly, and that is that if the fixed charges are to be handled by the sales agent of the central station as indicated in this paper, there seems no good reason why the fixed charges on the central station should not be handled in a corresponding way. Certainly the central station has to figure on the profit ratio if the industrial plant has to; and further the amortization rate in a central station is higher than in most industrial plants, for the machines are usually far harder worked and also are scrapped much earlier in their life. These points taken into consideration, there seems no reason to believe that the fixed charges against a central station should be much if any less than against an industrial plant. I have figured that the

Marginal interest would be	5	per cent
Amortization practically	5	per cent
Taxes and insurance	2	per cent
Fair profit ratio	11	per cent
Making a total of	23	per cent

Digitized by Google

On this as a basis I have made an examination into the reports of one or two of the lighting companies and taking their own figures as regards the cost of the plant, including real estate, one-half of which has been charged against the plant—steam plant, electric plant, electric lines including transformers, meters and arc lamps, and have charged 23 per cent against these. I have taken the operating expenses including station, distribution and management. I have taken the income as given in this report, which undoubtedly includes not only the income from the sale of current, but other sources of income. I have also taken into account the total kilowatt hours generated as given in the report, and the total kilowatt hours sold. From these figures we discover that this Company has received for total kilowatt hours generated, remuneration at the rate of 4.7 cents per kw-hr. They have received per kw-hr. sold, 6.6 cents.

Their expenses have been:

Operating, including distribution and management per kw-hr. generated	2.5	cents
Per kw-hr. sold	3.5	cents
On their fixed charges, the cost of kw-hr. generated is	4.7	cents
Per kw-hr. sold	6.5	cents
Making the total cost of their power per kw-hr. generated	7.3	cents
Per kw-hr. sold	10.0	cents

Evidently then, the central station or this particular central station is operating as a philanthropic enterprise, furnishing power purely for the love of it, because it is quite evident from these figures they are operating at a loss. Nevertheless the stock of this central station stands at a very high figure in the market, and the company is paying large dividends. Evidently they do not use the same basis of figuring as Mr. Parker would have the sales agent of the company use when figuring the cost of power for any industrial enterprise.

I would like to ask, therefore, the central station argument for charging by one method against the central station, and by another method against the industrial plant.

Mr. Kelley: Mr. Hibner states, in regard to power used, "Nearly all of them will tell you that their load is absolutely constant." Another point that they will tell you, if you are seeking to obtain data for a power estimate of their requirements, is that their machinery runs very steadily. I recall one instance where it was necessary to estimate as closely as possible on the probable requirements of the customer in order to conclude a contract. From my own data I took the power required for the machinery, and I went to the proprietor for information as to the time the different classes of machinery had been in operation. Taking that data and working it out I found my power cost was very much higher than I knew it should be in that plant, and by putting a man in that plant with a stop watch on each class of

Digitized by Google

machinery for two days I found that in some instances the time he had given was actually four times the actual time that machinery was in operation. To give you the conclusion of that affair, the contract was made by the central station with the party on these terms: that the estimated power consumption, if he allowed the central station to place his motors and to make the installation themselves, would be about $50 a month. The central station would put in the plant at its own expense, let him run it a year, paying the bills rendered, and if he was not satisfied at the end of the year would take out the plant at no expense to him except for the power taken. I recollect that the average of the first six months was $47.75 that was paid for the plant at that time. It illustrates the accuracy with which the cost of operating an industrial plant can be predetermined if the factors are all given proper value.

In regard to the statement given in the paper, the difference in cost, or reduction of cost, by a differing use of steam in a steam plant. I can give you the results of power cost estimates that have recently come under my observation. In one case it was that of a plant operating about 1,000 lights and 55 h.p. in motors. The plant used current both for light and power, and mechanical use of steam, for the 24 hr., of course in varying quantities.

The plant consisted of one 125-h.p. engine, 275 rev. per min., direct coupled to a 75-kw. generator, and a 40-h.p. engine direct coupled to a 25-kw. generator. The total of costs for the year, including all the items that have been included in these estimates previously given, was 2.022 cents per kw-hr. That is rather a surprising cost, and it is simply due to the 24-hr. operation and the large use of steam, which reduced the power cost materially over what it would have been if this mechanical use of steam had not existed. That illustrates the fact that almost every industrial plant must be valuated on its own basis; you can't use averages.

For another plant the data is roughly as follows: the total power required was about 1,000 h.p. The water power available varied from 200 h.p. to 400 h.p. and the difference in the amount of industrial power demanded during different seasons of the year ranged as high as 200 h.p., this making a possible maximum variation of about 400 h.p. These conditions were looked into by a central station that desired to provide power. The proposed installation called for a maximum of 500 kw., with an average yearly power of 380 kw., and the price named was something under $30 per h.p., without stating where the power was to be measured. The cost of that plant as it was operating at the time the data was taken was about $27.50 per i.h.p. With a plant laid out aggregating about 790-h.p. in motors, there being 91 in number, and the steam plant re-organized on the basis of the most economical operation, the cost figured out 1.485 cents per kw-hr. The items covered in that estimate are

Digitized by Google

coal, labor, miscellaneous, supplies, oil, removal of ashes, repairs, interest, the amortization, insurance—both regular boiler insurance and liability insurance—taxes, charges on three months supply of coal, and the charge for supervision.

Another plant had some 500 h.p.—I think exactly 523 h.p.—in motors installed. The company was buying power. It was at the same time operating 500-h.p. in boilers, and supposed it was using steam economically for mechanical purposes for an engine of 75-h.p. and various pumps. Their annual bill for light and power was something over $13,000. By a proper installation on its own premises it reduced the cost of power from $2\frac{1}{2}$ cents per kw-hr. to one cent a kw-hr.

So you can see that every plant must be valuated, upon its own conditions, and all conditions must be taken into account.

John West: The question upon which Mr. Hibner has based his paper, " The Cost of Industrial Power " is " Shall I purchase my power from a power company, or are my conditions such that I can produce it cheaper myself." Mr. Hibner has answered this question by a very accurate estimate of the additional cost for power in the operation of the proposed steam plant. I think, however, that those industrial power engineers who are employed by central stations will agree that the marginal difference between the cost for central station electric power and the cost of manufacturing power in a private plant is in many instances very slight. The facts that live steam for industrial heating, large demands for factory lighting, and the use of factory residue for fuel, enter largely into many industrial power propositions make such conditions typical of the average problem; and to what extent these items will affect the cost of producing power is dependent entirely upon many conditions, as Mr. Hibner has pointed out. This does not mean, however, that the central station industrial power engineer is justified in abandoning his efforts to obtain power business when such conditions are encountered and the engineering data obtained proves discouraging.

It has been proven beyond a doubt that through the use of central station electric power service, certain economies are effected the value of which should be taken into consideration and used to offset the conditions which would seem to prohibit the use of central station power.

While we are considering the manufacturers' lack of technical knowledge and his inability to determine the cost of industrial power it should be remembered that the majority of manufacturers look at the cost of power from the standpoint of its relation to the total cost of production, and for the sake of convenience usually combine light, power and heat to one account. Their figures may be in error from an engineering standpoint, but the fact remains that if a manufacturer considers that his plant investment has paid for itself, and if his credit standing is such that funds are available to the amount necessary to replace his equipment, it is likely to require conclusive proof of the

Digitized by Google

benefits which he will derive from central station power service in order to obtain his business. Therefore, it is my personal opinion that industrial power engineers engaged in central station work should regard the cost of power from as near the manufacturer's point of view as it is possible to do, and base their arguments upon the economy which central station power represents.

The highest possible price for central station power service should be the result of industrial power engineering; and the true cost of power would seem to be a relative factor in which the value of the service should be considered.

In order to show the value of central station service it is sometimes necessary to make comparisons of economy between manufacturers who are competing in local markets, and the value of such comparisons is of course confined to local application. I have in mind the operation of two manufacturing concerns. Their methods of operation are almost identical and each believes that his operation has approached its highest efficiency. One of these manufacturers has a steam power plant located in the basement of his factory from which steam for heating and manufacturing purposes is supplied and power transmitted to the machinery by mechanical drive. Factory lighting is supplied from a generator which is driven from the engine. The rate capacity of this plant would be 150 kw., and it is being operated at very near full capacity. The other manufacturer employs central station service for power and lighting and maintains a heating plant for factory and industrial heating. A large part of the exhaust steam in the private plant is used for heating, factory residue represents a large portion of the fuel, and the cost of industrial power and light is reduced to a very low figure. In contrast with this figure the rate which the electric company received from the other manufacturer for power and light is high.

Such a comparison would seem to indicate that the private steam plant is the better proposition. By a careful investigation of the gross yearly valuation of the product of each factory and an adjustment of the quality of the products to the cost for power, heat and light it may be shown that the total cost of these three items would represent approximately one-half of 1 per cent of the gross valuation of the product in either case. This bears out the assumption that the cost for industrial power whether obtained from a central station or manufactured in a private power plant will result in approximately the same economy for similar conditions of operation. In this particular instance it becomes necessary to employ some such method of presenting the cost equalizing advantages to be derived from central station service in order to prevent the loss of the business of this central station customer and his neighbors and to forestall the installation of a suggested private steam electric plant to supply light, heat and power for the several manufacturing plants that come in the legal limits.

Digitized by Google

In reducing the cost of power to an economy basis the chances for error are of course increased, but from a commercial standpoint my experience leads me to believe that the human element enters at this point, and its attitude which has resulted, according to Mr. Hibner's explanation, from ignorance of technical detail, and the desire to reduce the cost of production may be turned to the advantage of the central station power service without misrepresentation of facts.

Mr. Lundgaard has stated in his discussion that Mr. Hibner's paper has been very clear in defining the various factors and really does not leave much to be said when the discussion is limited only to cost. I quite agree with him in that Mr. Hibner has accurately qualified his assumption.

I think however that while, with reference to geographical location, the example he has chosen may be " a typical example of the conditions ordinarily found," it rather serves to exemplify an excellent opportunity for the installation of central station service, than to typify the general average industrial power problem. A commercial load factor of 80 per cent is not unusual for 10-hr. operation in shoe factories but is not generally found when a period of 3000-hr. is considered. The relation of power cost to power value is unnecessary from the central station viewpoint in this example, but if we admit that central station power service would result in an increased production over the use of similar service from a private steam electric plant we are able to arrive at some interesting results. I have assumed that the increased production in this case would amount to 1 per cent for an equal amount of energy consumed. If the gross yearly valuation of the product of the Toronto shoe factory would amount to $1,000,000 and the net profits 25 per cent then this 1 per cent increase in production amounts to $2,500 which has the effect of reducing the cost of power 45.4 per cent. It is not unreasonable to suppose that such advantages as the use of the elevators during the noon hour and for overtime work to facilitate shipment of product and the convenient handling of materials, and the security afforded against shut-downs which will enable the safe working capacity to be increased, together with the continuous coöperation of central station engineers in effecting the highest efficiency of application would result in this increase of production.

If we disregard those advantages which are distinctively inherent to central station power service and which may be said to result in a better quality of power than it is possible to obtain from any other source, we are sure to weaken the position of central station power. We would not seem to be doing full justice to the subject of the cost of industrial power if we excluded the value of quality; and without a standard of economy upon which to base our comparisons of costs I feel safe in the assertion that much power business will be lost to central stations.

Digitized by Google

C. A. Adams: These papers are very interesting from several points of view. They are encouraging in that they are frank and earnest efforts to reduce to a more rational and scientific basis the computation of the real cost of power; but, when coupled with the discussion, they are very discouraging in that the opinions expressed by various speakers of broad experience and high standing in the profession differ so astoundingly on the vital point at issue, and almost always in the direction of the economic interests of the speaker; in other words it is an illustration of the old theory of economic determinism. It would seem that of all men, engineers from their experience in close contact with the unchangeable laws of nature should be able to see such problems apart from their commercial interest.

Referring now more specifically to the papers, Mr. Hibner appears to have neglected one consideration which may be of considerable import. When considering the cost of power it is very important to know how much of the exhaust steam is used for heating or for industrial purposes and how much of it is wasted; but to this end it is not sufficient to know the relative monthly or daily demand of steam for power and other purposes, since it is quite possible that where the demand for industrial steam during the regular working day considerably exceeds the demand for power steam during the same period, some of the exhaust steam may, nevertheless, be wasted owing to the lack of coincidence of the peaks of the demand curves for industrial and power steam. I know of plants where this is actually the case and where it means an appreciable increase in the real cost of power.

Turn now to the question of profit and the marginal principle referred to in Mr. Parker's paper. The principle involved and its application to the commutation of the cost of power is unassailable, but the opinion as to a fair profit (11 per cent) over and above the 6 per cent interest is one with which I cannot agree. The assumption that the average promotor or investor is not attracted by less than 17 per cent return on his investment is somewhat astounding to those who consider themselves mighty lucky to get 6 per cent. If central stations earn 17 per cent, which I do not believe, it is no wonder that we have so much agitation for public ownership.

Moreover if the promotor or owner of a plant stops his investment when the marginal investment ceases to earn 17 per cent, it is to be assumed that he can place any additional capital he may have at that figure. Why then should not the amount set aside for amortization be earning 17 per cent rather than 6 per cent which is considered too high by many.

Since the profit ratio is a quantity concerning which there is a wide difference of opinion, and since the 6 per cent interest is fairly well agreed upon, would it not be better to exclude the profit from the fixed charges in figuring cost of power. This would reduce power-cost to a parity with the cost of other

Digitized by Google

things,—what we have to pay for them. Then the profit in the manufacture of power could be figured for each case, and if it fell below the desired point, the proposition would be discarded as not yielding enough profit. The result is obviously the same, but the method here proposed would eliminate a large amount of unnecessary and profitless discussion.

I have here some figures on the cost of power in a particular plant which may be of interest. It is the case of an industrial establishment where the total amount of steam consumed is vastly in excess of the amount required for power, and where all the exhaust steam is utilized. Including even the 17 per cent (6 per cent interest and 11 per cent profit) fixed charge in addition to insurance, taxes and amortization, the total cost of power per kilowatt hour is only 9/10 of a cent; and without the profit, simply charging 6 per cent interest on the money, the actual cost of power comes to about 56/100 of a cent a kilowatt hour. These are not figures concerning which there is any doubt, everything has been allowed for. The reason for the low cost is that the plant runs 144 hours per week at a load factor of at least 80 per cent and all of the exhaust steam is used for industrial purposes.

N. T. Wilcox: What is the price of coal?

C. A. Adams: The price of coal is $2.20 and the plant is on tide water.

J. F. Vaughan: Referring to Mr. Adams' discussion of fixed charges, it is common in new enterprises to divide the interest item into two parts; one, straight interest for raising the money, and the other a certain percentage for covering the risk of investment. It would seem reasonable in comparing a central station with some isolated plant to allow the same percentage for covering the "reasonable risk" in each case. In a going system, however, allowance for such risk is not justified except in cases of considerable extension or a development of new business.

There is one point that I should like to refer to in Mr. Dudley's discussion at Toronto, of Mr. Hibner's paper, and that is the ambiguity of the term "horse power year" as ordinarily used. He brings out clearly that this term means nothing unless the load factor is stated. He gives some interesting data on this question of load factor in manufacturing plants of various kinds; for instance, the load factor for cement mills is given as 85 per cent, textile mills, cotton mills, etc., 75 per cent to 90 per cent, and so on.

C. A. Adams: They are 10-hr. load factors, are they not?

J. F. Vaughan: They appear to be 10-hr. load factors.

Mr. Cook: I would say that one of the points to be considered is whether it is 10-h.p. or 10,000 h.p. and these figures that Professor Adams presented don't mean very much to me unless we know how large the plant is.

C. A. Adams: 1000 h.p.

Digitized by Google

Thomas M. Roberts: I should like to put one of the first sentences of Mr. Parker's paper with one of the final sentences of Mr. Hibner's. Mr. Parker speaks in regard to the fixed costs being determined somewhat by the *first layout*, and Mr. Hibner's paper in the final sentence in regard to the time in the future when no factory will be without its *consulting engineer*. I have just recently had occasion to visit one of the large mills of New England, and the agent for the mill being one of the shrewdest business men, probably, in New England, and he sees immediately where advantage is gained by putting capital into the right investment to improve his electrical equipment for his mills. When it is pointed out that although an underground system will cost more than twice as much as a pole line system to distribute the power of the mills he immediately sees the advantage of that underground system, in that the cables can be put closer together, less copper is involved in carrying the power some 1,000 or 1,500 ft., and the maintenance of the underground system when once installed is very small, in fact it is there to eternity, relatively speaking, by the side of other apparatus; and he sees in figuring up his coal bill that in the course of a year on something like $60,000 worth of coal he can gain $\frac{3}{4}$ of 1 per cent, say, on the investment, by putting things underground instead of overhead. Well, that is a margin, and it is worth financiers' notice.

The cost of copper now is low; we don't know what is liable to happen. It is liable to go back to where it was a few years ago, up to 20 cents a pound. And yet the first cost of apparatus in transmission is a very decided factor in the problem here, although this paper does not discuss that end of it. It seems to me that the first installation, properly installed, means a very marked factor in the fixed costs on the coal bill. I have come across many cases where a plant is already installed and a manager wants to supplement it with new motors, he will say, " Here, we have running through the mill so many circular mils of copper and it is not half loaded yet according to the insurance rules." Well, when we come to figure out the amount of copper he has, and the voltage drop, if it is alternating current (the reactance factor running perhaps nearly three times as much as the resistance factor), we find unless he adds considerably more copper he will not get the right voltage delivered to the motors. That brings up the question of voltage, or the main factor in transmission. A large portion of the mills throughout New England are based on 600 volts at the switchboard and 550 at the motors, yet there are quite a number that are not afraid of 2300. It means not only fulfilling insurance rules, but it means a decidedly less first cost on the copper; it means a decidedly less $I^2 R$ loss, which is continually eating up the coal bill; and the time may come, (and I feel quite confident personally that it will come), when 6,600 will be delivered into the mills instead of 600 or 2300. It is simply a matter of educating the general engineering public,

Digitized by Google

and especially the fire insurance people, to the fact that it is no more dangerous, so far as the risk is concerned, when properly installed, than the lower voltages.

It seems to me, as engineers, we cannot dodge this question of getting the power from the centre to the consumers, or to the receiving units at low cost; and that it is poor economy for a consulting engineer in laying out a plant to put the power house down by the water unless he can balance up against it the additional cost of transmitting the energy to the center. Let me put that another way. Let us suppose that the central power station, at the mills, is near the water, and it is also at one end of the mills. Now, the consulting engineer must balance up the advantage of being near the water for condensing purposes and delivery of coal, against the added cost of transmitting the energy, say several hundred or a thousand feet, as the case may be, to the farthest mills; while if he puts the plant in the center of distribution and carries his coal a little farther, and first puts up the price of an extra circulating pump, or something of that sort, in his auxiliaries, he may find—and certainly putting the costs side by side he will find—that it is better in the end to put his power station in the center of distribution rather than down by the water to save the cost of a circulating pump. To me these factors are coming up continually in meeting the extension equipments and new equipments in New England mills, and it seems to me are overlooked very largely by the manufacturers themselves.

F. M. Gunby: The cost of power has been discussed to quite an extent, both as to the gross and net costs. But the cases sighted, in which part of the by-products of the steam plant were used for heating and manufacturing, were confined mostly to plants in which heating only was required.

I wish to say something about the credits to the cost of power in plants where more of the by-products of the steam plant are made use of. The net cost of power to a manufacturing concern is the gross cost of power minus the costs of all of the waste products which are made use of in the manufacturing process.

These remarks refer principally to plants of fair sizes, such as might be found in textile mills. By fair sizes, we mean 500 or 1000 kw. and upwards. I will refer below to " bleeding " steam, by which I mean steam which is taken from between the cylinders of a compound engine or from between the stages, or parts corresponding to stages, in turbines.

Mr. Charles T. Main stated in his paper entitled " Choice of Power for Textile Mills," read before the National Association of Cotton Manufacturers in 1910, that the gross cost of power might be reduced by the amounts given in the table below by the use of steam bled in the manner described. This table was made up originally to apply to steam engines, but is also practically applicable to turbines with slight modifications:

Digitized by Google

Per cent of steam used (bled)	Coal at $5 per long ton per kilowatt year	Coal at $4 per long ton per kilowatt year
25	$3.00 to $4.00	$2.40 to $3.20
50	6.00 " 8.00	4.80 " 6.40
75	9.50 " 12.00	7.60 " 9.60
100	12.50 " 16.00	10.00 " 12.00

We recently had occasion to analyze the cost of power of a plant which was in operation, where a considerable part of the hot water from the condenser was used in the dye house and about 30 per cent of the steam to the high pressure cylinder was taken out at the receiver and used for heating the buildings in winter. This analysis was made by conducting several tests on the plant and also by obtaining information from the station reports and mill books. In this case the gross cost of power was reduced, due to the credits for heat units used in manufacturing by about 23 per cent.

In some plants it is possible to greatly increase these credits by bleeding more steam or even by running non-condensing. In this particular plant to introduce these further refinements would have led to two systems of steam piping in the dye house, as only part of the processes could use exhaust steam, and also it was found that the help in this particular plant were accustomed to using high pressure steam in their machines. Any oil in the manufacturing steam was also objectionable and at the time that the plant was installed, the bleeding of turbines was unfavorably regarded by the turbine builders.

It is interesting to note in connection with the operation of this plant that twelve boilers are run daily, while the steam going to the engine requires the output of only two boilers.

Another manufacturing plant of the same type as the above, where the mill help is accustomed to the use of low pressure steam, is installing a turbine plant where about one-half of the steam power will be obtained from non-condensing turbines and turbines from which steam may be bled. The rest of the steam power will be obtained from condensing turbines, thus giving a very flexible arrangement. Part of the hot water from the condensing machines will be used for manufacturing processes.

Credits to power in this plant will be a great deal more than the above. The actual cost of coal for power will be represented by the work done and the losses in the turbines and piping to and from them, and in such warm water as goes to waste.

While the proportion of the turbines installed in the past which have steam bled from them is not nearly so great as that of the engines, in this section, it would seem that bleeding turbines should prove to have greater advantages than bleeding engines.

1. Because there is probably less B.t.u. loss, due to condensation in a turbine than in an engine.

Digitized by Google

2. Because the steam bled from a turbine is free from oil, which might soil the manufactured product. This, of course, is not the case with an engine on account of the cylinder oil.

It is very gratifying to see that the turbine builders are coming to realize these facts and are modifying their designs to facilitate this bleeding.

J. C. Parker: The discussion has been so extensive that it does not seem that the author could add anything in closing except to emphasize and possibly explain some of the points on which differences of opinion have arisen.

These very differences of opinion have been a source of disquietude to one of the speakers. To the author, however, it is rather satisfactory to note that these differences have arisen, since they have at the least indicated that the paper does not deal with a subject on which there is so great unanimity as to make a discussion unprofitable, nor does the author feel that these differences are surprising. Human knowledge is always increased by going from the things that we know intimately to the things that are less familiar and in the process there is always a similarity to or differentiation from the things that we have believed in the past, so that it is not surprising that Mr. Moses, whose work has been in one field; Mr. Williams, whose work is in the same field as the author's but in a different locality, and the author, should arrive at somewhat different conclusions as to different data. The author is sure that as we all progress in knowledge, we will come together more and more closely, approaching the limit from many different directions.

It does not seem worth while to discuss in detail the numerical data presented by the various gentlemen who have contributed to the discussion. It is all interesting and valuable when weighed with relation to the point of attack and the inevitable predisposition which in even abstractly scientific work subconsciously influences the observer. That the author's own data is influenced by such considerations he would not for a moment attempt to deny but he is not sure as to the side on which he errs. In the attempt to make the data conservative he would be influenced to find low first cost and low operating cost, while on the other hand, were the wish father to the thought, he would naturally believe that both investment and operating costs are very high.

He does believe, however, that estimates based upon operation over a period of years are more conclusive than test data gathered from a ten or twenty-four hour test when firemen and enginemen are naturally endeavoring to make as good a showing as possible for the plant, and during which it is very hard to accurately determine banking coal and impossible to ascertain supplies, repairs, etc. Similarly it is almost impossible to make an estimate of the first cost of a plant from an addition of the constituent items, in which even a skilled engineer may readily fail to incorporate a mass of small but, in the aggregate

Digitized by Google

expensive details entering into the plant. In so many cases has the author found the actual facts to be widely variant from pre-estimates and from short period test data that he is forced regretfully to confess the inadequacy of such methods.

The author would like to direct attention again to the fact that, while apparently high, all the installation figures given in his paper are from actual quotation and the operating costs are based on observation of a very large number of plants actually run for a period of years. In connection with the latter it should be noted that adequate book-keeping is distinctly the exception rather than the rule and that where bookkeeping has been accurately carried out, the cost of repairs, etc., is invariably shown to be much higher than where the usual and slipshod methods have been pursued.

Considerable discussion has attached to the operation of the marginal principal with reference to both managerial time and fixed investment.

While it may betoken bad management, the author's observation has been that, whether they should or not, managers give a very great amount of time to the operation of their engine plants. It may be that this in part arises from the eternal boy in even the most serious minded adults, and it may be that an able man could not be employed on even an ample salary to devote his life to the supervision of 200 or 300 h.p. of apparatus.

That such time should be charged with only its fair salary value seems to the author a fallacious contention. He does not believe that the owner of an establishment would employ a $10,000 manager unless the owner expected to make or to save two or three times that amount as a justification for employing him, and it certainly involves a loss of whatever would have been gained when such a manager's time is diverted to other activities without producing such a gain.

The same reasoning applies to capital invested. Many a time has every business man expressed himself by saying that he cannot afford to put money into a certain venture because he will make so much more by putting it into the venture which he already has. The same reasoning must apply to the details within the business.

Some of the gentlemen discussing the paper have evidently misapprehended the operation of the margin in that they have claimed that there are very few businesses that would pay as big a profit as the author has assessed against an isolated plant. This is perfectly true and applies to the central station business as well as to the industrial and mercantile pursuits. A study of the curve given in the paper will indicate that certain essential factors in the business are, as brought out by Mr. Peck, non-productive and must, whether one will or no, be taken at a loss in order to put the owner in a position where he can discharge the ultimate functions of the business. As shown by the curve, such features reduce the average profit perhaps much

Digitized by Google

below that obtaining at the margin, which is in itself a constantly decreasing amount.

Reference has been made to the fair profit for the central station. The author agrees with several of the speakers, that assuming an *average* profit of 11 per cent, almost every central station in the country would appear as a charitable institution, but after noting that the average profit is very much lower than the marginal profit we may note one other fact; namely, that the margin of profit is determined by the individual and by the business and is different for different individuals and different industries, being always defined, as noted in the paper, as the most that can be got in any other business of which the promoter has knowledge. The public utilities art being practically a standardized and assured one with relatively small local competition, the proprietors suffer less risk of total failure than do the proprietors of an industry that may be more or less new and untried and where local or outside competition, operating through the channel of transportation and changes in the public whim, may at any time precipitate financial disaster. This fact is illustrated by a reference to the conditions obtaining in stock exchange quotations of industrials and of railroad securities.

That the amortization fund should not bear interest at the normal interest rate plus the fair profit rate seems to the author to be an entirely correct proposition, since while the amortization fund may be reinvested in the business, it is simply a case of the firm borrowing money for the business from its own amortization fund at the market rate, and while such borrowings may and properly should pay the same fair profit as any other borrowed money, this extra earning is properly creditable to the business as an inducement for borrowing and investment.

Aldis E. Hibner: In concluding the discussion which has been so valuable in demonstrating the different view points of those dealing with industrial power costs, I wish merely to explain my own point of view more fully where it seems to have been misunderstood by the various speakers.

In the first place, mention has been made concerning the selection of an 80 per cent load factor. It is obvious that some basis for calculation must be assumed and this value was selected as fitting the case of a shoe factory from which my example was derived. As pointed out, this is higher than can ordinarily be obtained and for that reason a curve was plotted in Fig. 3 giving the cost of power for any other load factor.

Mr. Arthur Williams in his discussion has assumed that the heating load was 62 h.p. If reference is made to Fig. 1 it will be seen that the average heating load is 44 h.p. As to the amount of coal required for heating, the conditions vary so enormously that each problem requires special treatment. For the particular case the writer had in mind in his example 475 tons for the heating season is not excessive. The object of charging full time for a fireman for heating the building is given in the

Digitized by Google

paper. We can only charge against the cost of power the actual additional expense incurred by its generation.

The example of power costs from fifteen plants given by Mr. John H. Norris might be of considerable value if given more in details. As the figures stand at present, however, they are of little value as in numerous instances the price of the fuel is not given. In the case of Plant No. 12 the fuel cost is taken at 0.3 cent per kw-hr. whereas the results of the tests given in the plant show a fuel cost of 0.47 cent in one case and 0.69 cent in the other.

Also in the case of Plant 15 the cost of fuel is taken at 0.17 cent in one place whereas in the results of the test in this plant the fuel cost is given at 0.42 cent. Furthermore, only 10 per cent is figured to cover the fixed cost of a gas engine plant and this should, in the writer's opinion, be raised to at least 15 per cent.

In answer to Mr. Tillman's question regarding the items of coal for night heating and for banking, I would say that the coal for night heating is the additional amount required for heating the building during the winter months over and above what would be required for simply banking the boilers over night.

In conclusion I wish to emphasize what Mr. Jackson has said regarding the imperative demand for detailed figures in comparing power costs. Much data that would be very valuable is made worthless by lack of detail on points of vital importance.

Digitized by Google

A paper presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, June 27, 1911.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

RESPONSIBILITIES OF ELECTRICAL ENGINEERS IN MAKING APPRAISALS

BY H. M. BYLLESBY

In approaching this highly involved subject, I desire to call your attention to the wonderful achievements of our profession. Broadly, our profession is little more than thirty years old. It is true that telegraphy in its various applications and other similar branches had reached a great development at the date I consider as having been that of the birth of the electrical engineering profession in its modern sense. It is also true that the telephone at that time had come into existence as an achieved invention, but it was then purely an invention and lacking in the vast refinements and additions which have made it the huge engine of commerce and intimate feature of our modern life today. In the brief period of from thirty to thirty-four years, the profession of electrical engineering as applied to the generation, the transportation and the utilization of large quantities of electricity has come into existence.

In that brief period the wonderful achievements of electrical engineering, as just defined, have been accomplished. In the broadest sense of the term this development has required the creation of a new art. From the electrical generators of the Commonwealth Edison Company of Chicago, which are this evening furnishing the light and much of the stationary power and the bulk of the power for the movement of the intramural transportation of our great city, with a capacity of 30,000 h.p. per generator, to the generator of 30 or 34 years ago with a capacity of 50 h.p. is a far cry and a long distance.

The electrical transmission systems of thirty years ago comprised at best a few miles for supplying arc lamps and maximum

Digitized by Google

distances of about a mile used in the infant industry of lighting by incandescent lamps. To-day, transmission lines of over 200 miles are not uncommon.

At the birth of our profession probably the largest steam engine did not exceed an indicated capacity of 2,000 to 2,500 h.p. and engines of that capacity were extremely rare and confined almost exclusively to slow moving pumping operations. To-day we have reciprocating engines driving electrical generators of 10,000 h.p. capacity and steam turbines driving electrical generators of 30,000 h.p. Probably these sizes will be exceeded in the not distant future. I am calling your attention to this wonderful development; this creating of a new art and the attendant collateral developments of the subsidiary machinery and materials required, for the purpose of emphasizing the points which I wish to discuss very seriously. Among other achievements, directly or indirectly, of our profession has been the great development of the water wheel. It is probable that thirty years ago there was no water wheel in existence which developed substantially more than 500 h.p. To-day water wheels are in operation developing upwards of 15,000 h.p. for the purpose of driving electrical generating machinery.

Along with the achievements of our profession and taking its inspiration therefrom, and being forced thereto by our demands, has been a contemporaneous development of machine shop practice and machine tools. To-day there is a condition of accuracy, a necessity of working to microscopic measurements and a machine shop practice which did not exist before we required it and which I believe would not have existed today excepting to fulfill our exacting needs.

Likewise the foundry of today is producing steel and iron and bronze castings in quality, in size and in accuracy—all forced upon them by the advances of the electrical engineers' profession. The entire practice of hydraulic engineering, if not revolutionized, has been thrown forward by leaps and bounds by the requirements of the electrical engineers in the useful development of water powers for the purpose of generating electricity.

Along with this has gone the scientific and painstaking study of rainfall, of runoff, of careful detail investigation of natural precipitation through rain and snow fall, the action of ice in its various forms, the action of melting snow and the control, as far as humanly possible and on a wider scale than ever dreamed of in the past, of the Titanic forces of nature in swollen streams, floods

Digitized by Google

and cloudbursts. Storing water in reservoirs for the purpose of utilizing the stored or flood water at low water periods of the stream and the development of the reservoir on a scale heretofore unheard of have all been ancillary to the brains, the genius, the achievement of the men of our profession. The development of electric engineering has been a continued series of advances, step by step and leap by leap. There has been more obsolescence and more retirement of electrical machinery and tools and devices far in advance of their natural life, due to the continuing improvement, than has taken place in the history of or the development of any other art. The duties of the electrical engineer have been more eclectic, and I believe more exacting than those of any other profession.

A famous man of the world is said to have remarked during the most glorious period of the administration of the elder Pitt that "one had to look into the Gazette each morning to keep pace with the victories won." In our profession one has to read the daily press and carefully study the columns of the technical press to at all keep pace with the new developments, the new achievements and the new victories of the profession from which we all make our livelihoods. This tremendous growth from the dynamo of 50 h.p. to the generator of 30,000 h.p.; from the incandescent lamp as a luxurious curiosity to the incandescent lamp which is as much a feature of our modern civilization as our running water; from the transmission distances of a mile or two to transmission distances of 200 miles; from the electric motor existing as a laboratory toy to the electrical motor of universal use and of 10,000 to 15,000 h.p. has taken place within the span of years conventionally covered by the term a "generation." It has been achieved within the lifetime of most of the members present and it has occurred since the young manhood of many of us.

This is in truth a wonderful accomplishment. All who have contributed to it can justly take pride in the fact. It is probable the annals of civilization do not contain a parallel, but along with this proper pride, with the feeling of well merited satisfaction, let us not forget that collaterally and a part of it, something without which it could not have taken place, has been the work of the promoter and the banker. No new industry can be established, or when established can continue, and no art can grow to the dimensions of ours without the continued presence of the individual who supplies the capital, the money, the financial resource to the

Digitized by Google

inventor and the engineer. Large and continuing supplies of capital are required for research, for producing inventions, for the carrying out of the inventions and the development through their period of incipiency, of temporary failures and disappointments.

It is probable that thirty-four years ago there was not to exceed $1,000,000 invested in every feature and part of this art, and today, taking the entire civilized world, and in the absence of statistics, I believe that several billions of dollars would be short of the amount of capital invested in manufacturing plants, in generating stations, distribution systems, water powers, trolley roads, motors and subsidiary details employed in the business which has been produced by electrical engineers and the promoter and capitalist working hand in hand and together during approximately a generation.

I think we should seriously consider this fact; that we should give to the promoter, to the capitalist, to the man who is able to influence capital and to place it at the disposal of the men of our profession, the credit that is properly due him. The achievement of the electrical engineer would not have been possible if it had not been for the presence of the man with money who believed in the commercial possibilities of our art as from time to time developed and who produced the capital with which to continue the development of that art. I am entirely confident, although it is a matter purely of conjecture and not susceptible of direct proof, that inventions as great as any which have revolutionized the world have died, have never been heard from because the much abused capitalist was not on hand to stand behind the inventor during his period of discouragement and disaster. I believe many other worthy inventions and developments have attracted no great notice, have not accomplished their destiny because of the absence of the man or corporation with both faith in the invention and the means of producing the capital to develop it.

Our profession has indeed been fortunate in having had associated with it from its inception men who were sufficiently intelligent, courageous and far-sighted to see the merit of the inventions and developments which from time to time were produced and who had withal the faith and the ability to continue to stand behind these inventions and developments with their capital during that period which we all know has taken place, when these inventions and these developments were under criticism, temporary failure and while only disappointing results were being

Digitized by Google

reached. During this period of disappointment, of hazard, during this period of modifications from the original plans and disappointments and changes, the man or corporation with money was present to tide the infant invention or industry over the shoals and hazards which surrounded it, and except for the presence of men of the type of which I am speaking, with their courage, their faith, and their capital, many of the inventions and developments of our profession would have been in the grave of permanently disappointed hopes and non-fulfillment.

Today our art is developed. The product of the brains of the electrical engineer are so well known, their commercial utility is so thoroughly established, particularly in the principal lines of our achievements as to lead us to be forgetful perhaps of that period which the older ones of us recollect so clearly. This period, due partly to the crudity of our own devices and the undeveloped condition of our own inventions, due partly to the unstable condition of the collateral features upon which we depended such as steam engines, boilers, water wheels and manufactured articles, was a period attended with heart-breaking anxieties not only to the inventor and engineer, but do not forget that it was also a period of heart-breaking anxieties and disappointments to the man who had invested his capital in those things.

As I look back over the sweep of 30 to 34 years and from the standpoint of maturity which comes with middle age, and long experience, it is a continuing marvel to me that in spite of the perpetual disappointments and the hazards pertaining to this business, capital was found to proceed with the development of the art, and in all fairness as I look back over this period, the admiration I feel for the inventor and the engineer, the pride I take in their achievements is, in my own mind, shared with the courage and faith and enterprise of the men of capital who stood by us and our operations during those trying times.

Today there is a world of discussion regarding the value of a franchise, the terms of a franchise, the privileges it affords, the obligations it carries and the fraud which in the minds of the public is supposed always to be inseparably connected with anything bearing that name. There is much comment, nearly always unfavorable, regarding the conditions under which franchises for electric light, trolley roads and power transmission companies have been issued. If those who, probably with the best intentions possible, are criticising these matters had gone

Digitized by Google

through the experience of the earlier days, they would change their opinions. In the full blaze of the glorious noon in which we now find ourselves in our profession it may be difficult but it should not be impossible, to turn our gaze backward to the early struggling days of this art, and I believe that by doing so, a more just view of the situation will result.

In those days franchises were given freely. Any one who applied for a franchise would receive it and, as a rule, without burdensome restrictions. The community which was favored by having capital build for its service an electric light plant to furnish what they believed to be a luxury and which otherwise they would not have had, or a community which was favored by a company who in return for a franchise would spend the money necessary to change the cruel and totally inadequate intramural animal transportation of that town or city to an electric transportation system was properly and deservedly welcome. The only feeling on the part of the citizens of that community or the governing body issuing that franchise was one of thankfulness that the electric light or trolley line was to be given them and one of pity for the individual or corporation who was so foolish as to invest capital in such hazardous enterprises. The same remarks apply to the development of water power. These streams were not fully developed. Some were developed for mills, but generally for usage only during the daytime and far below the capacity of the stream.

Until recently the laws governing the ownership of the power in the stream were believed to be pretty fairly understood along the lines handed down from our Anglo-Saxon ancestors. The company or individual who came into the community and produced the capital to develop these streams was royally welcome and he was viewed generally with some wonderment regarding his financial obliquity, as in the case of the individual or corporation building the electric light plant or the trolley road. If a brief and unprejudiced study is made of the history of these earlier electric light, trolley and water power companies, it will be impossible to depart from the conviction that the persistence and courage of the promoter and capitalist who carried them through their earlier periods of disaster and lack of credit is quite as notable an achievement as that of the inventors and engineers who produced the physical and scientific part of these enterprises.

This enterprise and this courage which heretofore has been

Digitized by Google

wisely fostered by the commonwealth has given the United States of America the most universally extended, the best operated public utility plants in the world. In the vast majority of cases the service rendered by the corporations is furnished to the public—with superior service with its wide extensions—at less cost than in any other country. Various contributing causes have produced this result. Among these causes has been the natural inherent courage and enterprise of the American. In addition to this, however, have been the liberal franchise grants issued in the past and the freedom from onerous restrictions both for occupancy of streets and the purchase and development of water powers. A broad and liberal construction which has justified the issuance of stock which would eventually pay to the projectors and developers of these enterprises when they became successful something in addition and beyond a mere fair interest return on their investment has also had a profound influence upon giving to our country the best utility corporations of the world. Without these features this development with its low charge to the public could not have taken place. Due to these features it has taken place.

Throughout the older settled sections of our country scarcely a hamlet is without electricity for lighting and power and large sections of our farming and ranching lands are equally supplied. Due to the liberal policies in the past which allowed a reward to recompense the hazards and the courage when such hazard and courage had passed its period of financial loss, we have as a result in this country steam railroads, telegraph lines, telephone lines and gas service which in excellence of service, the extent of the service, and the price charged for such service are not equalled in the world. These broad and fair policies in the past have justified the public service corporations in extending their operations, properly expecting as a result of employing additional capital and as a compensation for the risks incurred in pledging their credit and the credit of the individuals behind these corporations, to receive an accruing profit when their enterprise and courage had been justified by results, the companies uniformly lowering from time to time the charge made for their service. No fault was found with the increasing returns upon the capital invested for the purposes and under the circumstances set forth, if at the same time the rates for service, which were already fair as compared with any other country, were being lowered.

In this way communities throughout our country are today

Digitized by Google

served with public utility commodities at an actual loss to the companies serving them. These communities pay no more for the commodity of the public service corporation than the thickly settled communities, the companies operating this service having been heretofore justified in providing the capital and extending their plants into non-productive fields, standing the immediate loss resulting from this policy in consideration of an ultimate profit when their brains and energy and courage had been justified (if it was justified) by the upbuilding of these communities and the properly resulting profits then accruing. Bear in mind, as previously stated, that in the entire history of public service corporations in this country there has been heretofore a continuous lowering of the price charged for the commodity or service rendered to the public with the sole exception of the trolley roads, which started with a price to the public for service rendered which could not possibly be lowered and it is believed in many cases cannot be continued.

Abuses have taken place in the past on the part of the corporations, on the part of the public served by the corporations and on the part of the legislative and law administering bodies. At the present time my opinion is that both the public and corporation are reaching a common meeting ground, requiring public service corporations to be protected and regulated monopolies; these corporations to be governed as to their rates and to be protected from competition by so-called "public service commissions." With this doctrine as such, the public service engineer and operator has no quarrel. We do file a plea, however, that these public service commissions be composed of men of character, men of ability, men who have accomplished something in the world; that these commissions be composed of men who while fair and upright are conversant with the business which, under the laws governing their action, they are controlling.

The abuses which have undoubtedly taken place in the dealings between the municipal bodies and the public service corporations have been as distasteful to the corporations as to the public, and the cry of the corporations is for a fair hearing, for an intelligent hearing, for fair recognition of the benefits they have conferred and a demand to be relieved from the hardships and frauds which in many cases they have suffered at the hands of politicians a partially educated public sentiment and the municipal governing bodies. It is believed that properly constituted public service commissions, appointed for "good behavior," composed

Digitized by Google

of high-class men, suitably paid and operating under broad and liberal laws, will accomplish this much-to-be-desired object.

Granted, as I believe it must be, that the foregoing is a candid statement of the situation, the public should recognize that the so-called public service corporations should be encouraged and fostered instead of being strangled and discouraged. The widest latitude should be afforded the operations of public service corporations under monopoly and protection, and fair laws administered by conservative and able public service commissions.

Coming now specifically to the subject of my paper, the electrical engineer must recognize that in addition to the multiplicity of duties he has been called upon to discharge, he is now confronted with a new class of responsibilities from which he cannot shrink. To these responsibilities he must give the best that is in him of experience, of fair mindedness, of wisdom and of justice. In the world at large and particularly in the United States we appear to be in the midst of a period of flux and change.

Old methods and old standards are passing away; new methods and new standards are demanded. With the marvelous progress of the civilized world since the last great economic and social changes, it will be a shame if the present crisis fails of a solution more rational and with less hardship and destruction than has attended previous solutions of economic and social crises. Out of the present controversies we must endeavor manfully and fairly to bring a condition of justice to all concerned and in our share of duty in these matters we must make every effort to be intelligent and not to be found wanting in fair dealing and honesty between man and man, between corporations and the public and between governing bodies and corporations. Principal among these new responsibilities which are being rapidly thrust upon our profession is making appraisals to determine the value of the property of a public service corporation.

These values, in accordance with the unmistakable present trend of the times, are to be made a basis upon which or from which are fixed the maximum rates which these corporations are to be allowed to charge for service rendered. There is much discussion taking place on replacement values, reproduction values, depreciation values, and intangible values. In the majority of cases the property to be appraised represents a continuing growth or a construction period from its inception. Much of the construction work we are called upon to value is concealed from view, such as foundations of buildings, founda-

Digitized by Google

tions for machinery, submerged protions of hydraulic construction, conduit systems and gas pipes. In every case the structures or plants have been built in what is conventionally termed a " piecemeal " fashion. Almost every public service corporation has started from a small beginning and added to its plant continuously, and the finished structure today represents construction work which has been continued from the time the original property was created. In meeting the questions which the spirit of the times is demanding answers to, very properly a demand is made by all parties to the controversy that absolute and entire frankness and complete candor pervade the negotiations. Properly a period has been put to the practice of dissimulation and trickery and misrepresentation on the part of the public, the governing body, and the corporation. From a long experience I can state for my part that trickery and dissimulation and unfair dealing in the past have been fully as great on the part of the public and the governing bodies, if not greater, than on the part of the corporations. Following this proper demand for candor, I desire to call the attention of my fellow members of the American Institute of Electrical Engineers to the painful fact that it is extremely rare for a professional engineer or constructor in any branch of industry, in any branch of construction, to estimate the cost of such construction with accuracy and that the practically uniform experience has been that all such estimates have proved woefully less than the cost of the completed project.

I believe we should be candid and frank on the subject. Every one of us whose duties require him either as a principal or in an auxiliary capacity to be responsible for the furnishing of capital to build any given public service construction or to develop any given enterprise, knows full well from a long and painful experience that unless he provides for indefinite excess charges or leaves some other avenue of escape, the enterprise or construction when finished will be burdened with a floating debt which seldom is of small relative proportion. This debt is the difference between the estimated cost of building the undertaking and the actual cost as developed after the event. I believe there has not been a considerable piece of public service construction in recent years where the finished cost complete has not overrun the estimated cost by a minimum in a few cases of 10 per cent to 15 per cent to a maximum in a majority of cases of a dangerously large percentage which not infrequently has gone to an excess cost of 100 per cent. All experienced contractors will

Digitized by Google

bear out the statement I have made. The comparatively few contractors who finish their career with more money than they started with, or with more money than they themselves started with and without leaving their banks or guarantee companies in the lurch have an experience of profit and loss, the loss on one job the profit on another. These men have learned their lesson and today they will only with the greatest reluctance take a contract which, under an enforceable bond, compels them to fully complete any large given piece of work for a given sum of money. Where they are forced to take any part of their contract in this manner they very properly, I think, provide for extras at a given rate, expecting that their loss on the lump work will be made up by the profit from the extras. This is too thoroughly understood to admit of any discussion.

I shall not attempt to go into detail of this well-nigh universal experience of underestimating. A large total excess cost of a completed undertaking may be represented by a small overrun in the cost of the purely physical construction and an omission of large material collateral expenditures which are part and parcel of the completed project. The shortage may be due in this view of the case to an ignorance on the part of the individual furnishing the budget to be provided; ignorance which results in overlooking a material and proper part of the cost of the completed project because it was not strictly physical construction. The overrun resulting in the floating debt therefore, in many cases, may be quite largely made up of the omission of those necessary costs which in the discussions of the times are termed "intangible values." But no matter in what direction the shortage occurs, no matter whether on the strictly physical part of the construction or from forgetfulness or ignorance of the proper costs under the head of intangible values, the facts remain substantially as I have stated in my premise.

How careful, therefore, how fair minded and liberal should be the point of view of the professional engineer in appraising the value of another man's or another corporation's property for the solemn and serious purpose of having based upon his appraisal the return which that man or that corporation is to be allowed to receive upon his investment. It is unfair that an engineer or appraiser who recognizes at the bar of his own conscience that his own estimates have been uniformly overrun should make his appraisals without taking into consideration and manfully applying to his estimate his own factor of individual inaccuracy, his own personal factor of nearly unfailing underestimating.

Digitized by Google

If the profits to be allowed public service companies were to be on a broad and liberal basis this feature would be of less importance. The spirit of the times, brought around partly by mistakes, by selfishness, by unfairness, on the part of all parties to the contract, the tendency of the times, actuated to a degree by certain irresponsible magazine writers, magazines and papers, and by certain politicians, all tend to reduce the return of the public service corporation to a low point. At best it would indicate, allowing the public service corporation after paying its operating expenses and depreciation charges, a distributable sum equivalent to from 7 per cent to a possible 10 per cent upon its reproduction value, the higher percentage being rather hoped for than indicated. It becomes plainly evident, therefore, how grievous a hardship may be worked upon corporations if the appraisal of their property is as much below the real value of their property as the average estimate of the engineer has proven in the past. I think the situation is one of the most momentous which confronts our profession today. A large part, I presume 90 per cent, of the activities of our profession have resulted from the continuing growth and existence and development of public service corporations. If these corporations through under appraisals or drastic regulations are discouraged and cease their active aggressive growth of the past it will be immediately reflected in the lessening demands made for the services of the members of our profession.

Capital is a peculiarly mobile commodity. Capital will flow from one part of the world to another in accordance with the inducements which are offered it. Capital will leave any given field with great speed if it finds that it is receiving an unfair or unjust recompense or other fields offer greater inducements. Without capital, modern enterprise is impossible. The most beneficial use of capital is to have it employed in developing new enterprises, extending existing enterprises which in turn develop and add to the wealth of the communities served. In our extending enterprises we afford profitable employment for increasing population and we ameliorate the conditions of human existence. The profession in which the members of this association are engaged could not exist at all if capital withdrew its support from enterprises depending upon the genius and ability and conscientious effort of the electrical engineer.

I urge upon all of you to carefully consider this subject, to avoid the influence of the idea that the professional engineer can

Digitized by Google

get along without the services of capital. Capital on its part must treat the public, the laboring man and the professional man with fairness and liberality, with more fairness and liberality than it has in the past. On the other hand, the professional man who from the nature of his calling and its dignity carries a large influence in the community in which he operates must not forget the close co-relation between brains, labor and capital, and neither through professional indifference or professional jealousy allow himself to give capital an unfair hearing or an unjust decision.

We must avoid the fallacy that only the physical portion of a corporation's property is entitled to a value, a fallacy which has led many engineers, many business men and many corporations to disaster. The facts being that beyond the naked physical value there is required a very large and material sum to change that naked inert mass of physical construction into a live, progressive earning entity. The omission of the cost of making a going concern in addition to its naked physical value has been the root and cause, in my judgment, of a large proportion of the disasters which have overtaken enterprises in the field in which we operate.

These remarks and more to the same effect apply to the question of intangible values and when called upon to deal with these matters I hope the fullest consideration will be given to them. These intangible values generally embrace interest during construction, accidents and insurance during construction, engineering charges, supervision charges, and they should include proportionately, the tremendously large sums expended by public service corporations in developing the business, in educating the public, and producing a sale of their commodity, whose reflex effect in subsequent reduction of the operating charges should be considered as proper cost in the value of the property. Further proper charges, of an absolutely legitimate nature, to the intangible value account include the legal expenses of organization and of putting the enterprise on its feet, the discounts on securities sold or brokerage paid for finding of the capital and particularly in the case of the older companies, the large sums spent in absolute good faith in what was really a period of experimenting to obtain the best apparatus, the best systems, and methods adapted to the requirements of the company happening to be in question. Due regard should always be given to the added cost of piecemeal construction which has been an un-

Digitized by Google

failing incident of all of these corporations. In all fairness it should include the losses due to obsolescence and the discarding of workable machinery long before its life had been exhausted, this discarding being for the purpose of keeping pace with the times and in the last analysis for the better serving of the public.

There is a tendency, I hope a diminishing tendency, to be unfair to public service corporations and to be entirely oblivious of the hazards and risks they have incurred in the building of their business and to be forgetful of the profound importance and great benefit they have been to the communities they serve.

A recent example and a very pertinent one of this tendency to be unfair has occurred in the appraisal of the value of one of the largest utilities in a large western city. The appraisal was for the purpose of determining the proper reproduction or replacement value of this utility. The formula was rather clearly understood as pertained to the physical property, deductions were to be made and were made for the accrued depreciation, allowances were made for what had evidently been unusually expensive piecemeal construction and matters of that description, the theory being that as regarded the physical value of this property, its appraised value would represent what it would cost to reproduce the property in its present condition.

In general this formula was carried out fairly until it was found that a material part of the distributing system of this company was now under paved streets, but that due to the enterprise or necessity of the company in the past a part of its underground system had been placed in the streets in question before they were paved; that is, the paving above this underground system on a material portion of the company's property had taken place after its distribution system was in the ground. The ruling of the body making this appraisal was that this company was not entitled as a part of its value to the cost it would have been put to of placing this distribution system under the paved streets and the difficulty of sustaining this ruling is plainly evident from the fact that wherever this company has put its distributing system underneath paved streets or where it is doing it today, the cost of that paving has applied to this company and is allowed as a part of the value of its plant. It would be hard to conceive of a more direct effort to discourage enterprise than this particular ruling. If the company had waited to put all of its distributing system under the paved streets until the paving was down and had then ripped it up and buried its distributing

Digitized by Google

system it would have been allowed the cost of taking up and replacing the paving. Because it did it in advance it was not allowed that cost. This particular city is far better off from the course which that company pursued because its pavement over that particular portion of the distributing system was not injured by being taken up to put the distributing system underneath it.

We all believe we are approaching a far better understanding between all parties concerned on these questions than has existed in the past. The effort of all of us must be by conscientious effort, by candor and sincerity to bring around this better condition. However, with the tendency of the governing bodies to make decisions such as I have just referred to, how extremely important it becomes for the engineer entrusted with the making of an appraisal to be sure that he has not underestimated, to be sure that so far as his intelligence and authority go he gives to the property under consideration the benefit of all the value he believes it is entitled to, both physical and intangible.

In closing I desire to urge upon all of you a sense of the responsibilities now being thrust upon us; to urge upon you a sense of the dignity of our calling, and to express the hope that with the unusual opportunities possessed by the members of this organization for forming a basis for a proper measure of the questions of values; that we approach these subjects with high intelligence, with a profound sense of the responsibilities resting upon us and with appreciation of the fact that in the combination of capital, the public and professional engineers, no hardship can be worked to any one of the three without inevitably producing its full quota of disaster to the others.

Digitized by Google

Digitized by Google

A paper read before the Armour Institute of Technology Branch of the American Institute of Electrical Engineers, Chicago, May 11, 1911

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

ENGINEERING SPECIFICATIONS

BY FRANK F. FOWLE

The preparation of engineering specifications is a matter which the engineering graduate is likely to meet early in his experience. Therefore a knowledge of the subject and its relation to business law is important. Yet there is probably no subject which appeals less to the interest of the undergraduate student, or is more generally regarded as dry and tiresome. But modern theories of engineering education recognize clearly that a purely technical preparation cannot fit the engineer for the greatest sphere of usefulness, or the one which he should properly occupy.

The men in charge of large undertakings, and those in general who occupy responsible executive positions, are selected primarily because of their fitness in a business sense. Pure technical ability, without business capacity or experience, does not command a large remuneration. Such ability can always be had at a nominal figure and the supply is recruited each year, in large numbers, by the technical institutions of the country. But owners and investors will not trust their undertakings to inexperienced men, especially those inexperienced in the methods of business or commercial life and in directing the work of others. Of course it is well recognized that the engineering graduate has not attained the measure of a fully trained engineer, nor can he reach that goal without practical and commercial training.

In order to make his status clear to him, and to point out the things which his graduate training ought to embrace, it is both proper and essential to instruct him in business law and commercial practices. This cannot be a substitute for actual experience, in any case, but it bears to the engineer's larger sphere

Digitized by Google

of usefulness the same relation that the purely technical training bears to his purely scientific work, or engineering in the narrow sense. This point of view should not be construed as reducing the emphasis to be placed on purely technical training; that, of course, is fundamental. At the same time one should not become so absorbed with it as to lose sight of its proper relations to other things in life, or its correct relative importance.

Your course of instruction at this institution embraces both business law and contracts, however, so that further emphasis on their importance and value is not necessary. But the testimony of one speaking from experience may cause you to give these subjects more serious attention.

The Relation of Specifications to Contracts

A discourse on the subject of specifications is practically impossible without treating first of the broader subject of contracts, which underlies all engineering and is as old as civilization itself. The general purpose of a specification is to give an exact, definite description of certain work which is to be performed, so clear and precise that there shall be no doubt or uncertainty about the things which are desired and no opportunity for the performance of any work which is not wanted or intended. But the very presumption that a specification will be drawn implies first the intention to enter into a contract, and in general the specification will form a part of the contract.

The relation between specifications and contracts is therefore intimate and the two can only be separated with difficulty. In general there are two methods of preparing specifications: one is to make the specification an integral part of the contract; and the other is to make it a separate instrument appended to the contract. In either event the nature of contracts must be understood and at least an elementary knowledge of the law is very essential. But in any case of importance, particularly when competitive bids will be asked for by public advertisement, the contract should be drawn by one thoroughly versed and experienced in the law. The young engineer may well remember the old saying, "The man who is his own lawyer has a fool for a client," and forbear from attempting that for which he is not qualified.

It is not uncommon for lawyers and engineers to collaborate in important cases, in order to forestall future litigation and bring expert ability to bear upon every phase of the matter.

Digitized by Google

Most emphatically the engineer should not usurp the functions of the lawyer, any more than he would permit the reverse. Even in comparatively simple contracts, unless a standard legal form is adopted, it is an excellent precaution to have the legality properly passed upon. Litigation is both tedious and expensive, and nowhere is it more true than in respect to contracts that, " An ounce of prevention is worth a pound of cure."

The subject of contracts is a branch of law, and a very broad and comprehensive one. The layman may acquire a very good knowledge of it by extensive reading, which is recommended; and for that purpose a list of works is appended to this paper. It is only possible to give here the briefest outlines of the subject, to serve more as a general guide than for specific use.

Contracts in General

The definition of a contract has been stated as follows: " A contract is an agreement to do, or not to do, a particular thing." There are four essential and fundamental elements in any contract, as next stated.

1. Competency.
2. Legality.
3. Agreement.
4. Consideration.

Competency. The parties to the contract must be of legal age, sane and sober. In the case of corporations the contract must not contemplate any acts outside of the powers conferred by their charters. The laws of the several states name various disabilities, which should be known in any specific case.

Legality. Any act is illegal if forbidden by statute, or by the rules of common law, or if opposed to public policy.

Agreement. The parties to the contract must mutually assent to its terms and provisions and must understand them in the same sense; that is, they must be of the same mind and intent. If the meaning of the words in the contract is plain and evident, the law presumes it as such. In general, an offer and an acceptance are necessary to establish the existence of a contract.

Consideration. The consideration need not be stated, if it exists in fact. In engineering contracts, however, the consideration is almost invariably stated. The adequacy of consideration is not in evidence before a court, except in cases of gross injustice; if this were not the case, the courts would be overwhelmed with suits on the ground of inadequate consideration.

Digitized by Google

The parties to a contract enter into it "at their peril," and are presumed to weigh its terms carefully and fully before subscribing to it.

A contract may be oral or written, with equal force, but the first is sometimes hard to establish by reason of the lack of witnesses or evidence. Written contracts are classed under two heads; sealed contracts are those under seal, which is the required legal form in the case of gratuitous promises, conveyances of real estate and surety bonds, while unsealed contracts are termed contracts of record or parole agreements.

A contract can be modified by oral agreement regardless of provisions to the contrary, but the written form is much preferable. Much confusion and possible litigation can be avoided by adhering always to written agreements. This is an important point, because engineering works of any magnitude will rarely be executed in every detail as originally planned.

In drawing a contract it is the common supposition that it will be carried out in accordance with its terms. While this is the general rule, it is not always the case and it may be well to mention briefly the several ways in which a contract may be discharged.

Discharge

The several ways in which the contract obligations may be discharged are as follows:

1. Performance.
2. Agreement.
3. Impossibility of performance.
4. Operation of law.
5. Breach.

The discharge of a contract by any of the last three means is usually a matter which involves the technicalities of law and perhaps litigation, so that it hardly falls within the province of the engineer, aside from his informing himself on such matters for general guidance.

Advertisement for Bids

In many cases contracts and specifications are so prepared that bids may be publicly asked for by advertisement, with the object of letting the work to the lowest responsible bidder. This is sometimes made compulsory by law, as in the case of municipalities, public bodies, etc. Here it is essential to follow certain specified forms and carefully guard the rights and requirements

Digitized by Google

of the party letting the work. The advertisement should cover, in general, the following particulars.

1. A clear title and preamble, indicating the work to be done, and the person, firm or corporation letting the work.
2. A full description of the kind and quality of work.
3. Where to obtain plans, specifications and blank proposals.
4. The amount of the guaranty, in cash, certified check, or bond to accompany the bid.
5. How the work is to be let, in sections, or in whole.
6. The place, date and hour of closing the bids.
7. Reservation of the right to reject all bids.
8. A provision requiring bidders to show familiarity with and experience in the kinds of work to be let.

When the work is not of a public nature these requirements are not required by law, but in any case they form a valuable guide. In the case of private bids, the work may be let, of course, at the pleasure of the owner.

For those who are interested in further study of this phase of the subject, the forms used in various instances will be found in the standard text-books and authorities, given in the appended list.

Specifications in General

A specification has been defined as, "A written statement containing a minute description or enumeration of particulars." The exceeding breadth of this definition includes a specification for anything whatever, but we shall confine it to engineering works. But even with this limitation, the field is still immense. The treatment of the subject in all its details would vary with the particular branch of engineering considered. At the same time there are numerous general features which are common to all.

In general every engineering specification treats of two fundamental things; first, a full, minute and exact description of the work to be done and, second, the business relations of the parties to the agreement. This presumes that the contract and the specification will be one instrument. When that is not the case, the specification treats of the work alone.

As a whole there are three plans of proceeding with the preparation of a specification, as next enumerated.

1. Complete plans in detail.
2. General plan, only.
3. No plan whatever.

Digitized by Google

These three methods naturally fit different circumstances and conditions. The first is probably the safest one and most generally followed; it leaves no loopholes for misunderstandings and if the character of the work permits, is to be recommended. No responsibility rests on the contractor outside of performing the specific things called for, and the responsibility for the design and the general results rests entirely on the engineer. Wherever the design is such as to call for a large assortment of equipment, buildings, mains, etc., it is preferable to follow this plan, and usually necessary, because the character of design enters so vitally into final efficiency and performance.

The second method can be followed where details are not highly essential and stress can be laid particularly on the final results or performance. Here more responsibility is thrown on the contractor and less on the engineer; and in fact the contractor will usually be required to submit detail plans. It is then more essential that the contractor be a responsible person, firm or corporation, with a good reputation in all respects. This method applies particularly to machinery and equipment, such as boilers, engines, turbines, pumps, generators, motors, etc. In such cases the details of design are not essential except as they affect the strength, durability, efficiency and ease of making repairs. The engineer cannot afford the time, and moreover is perhaps not qualified, to go into great detail. The essential features are those already mentioned and the contractor should be required to submit his general design with the bid, including the details of all connections. The engineer is still responsible for the over-all results, but the contractor is made responsible for the characteristics and performance of his machinery and equipment.

The third or last method, without any specific plan, is essentially loose and likely to lead to bad results. It depends for success upon the undoubted ability and integrity of the contractor. It is often followed to some extent where the owner limits his expenditures for engineering to a very meagre amount, or even to nothing at all, and relies upon the contractor's engineer to furnish the design. In particular cases this may be safe, but not as a general rule. The owner is likely to find himself in a variety of difficulties unless he is very fortunate.

It is proper to refer here to the general relations of the engineer to the owner and the contractor. He is primarily the owner's representative, but at the same time he usually acts as mediator

Digitized by Google

and arbitrator. In one sense this is a dual position and the engineer should bear in mind the fact that any powers conferred upon him under the terms of the contract do not supersede or set aside the courts and the machinery of the law. There is essentially an element of injustice in appointing as an arbitrator, with absolute powers, a representative or agent of one of the parties at interest. The powers of the engineer should be carefully stated and he should be cautious both not to exceed them nor be unfair.

As a rule his duties in this respect are to supply any missing details and construe the meaning of any clauses which may be unintentionally obscure or doubtful. Much is gained by harmonious relations among all concerned and the engineer should strive to the utmost to attain and preserve them.

Any attempt to classify the elements of a specification along the lines of the main divisions or groups of engineering is extremely difficult, because no sharp lines can be drawn between the groups themselves. The knowledge of the electrical engineer must necessarily embrace much which is properly within the sphere of the mechanical engineer and the civil engineer. But for the purpose of giving a general perspective of the subject as it pertains to electrical engineering, the following classification may be useful. This applies only to constructed works in the electrical field.

1. Machinery and Equipment
   - Construction
   - Delivery
   - Installation
   - Performance

2. Electric Wiring
   - Inside
   - Outside
     - Aerial
     - Underground

3. Complete Plants
   - Light, heat and power.
   - Transmission.
   - Railway.
   - Telephony, telegraphy and signalling.
   - Electrochemical.

Of course specifications may be prepared to cover other subjects besides construction, but in the generally accepted meaning of the term, construction is implied.

There are no hard and fast rules in preparing specifications, and the engineer's judgment and experience come into play to a

Digitized by Google

great extent. It is a dangerous practice to copy from existing specifications in a blind fashion. The engineer should always satisfy himself thoroughly that clauses taken bodily from older specifications fit his case and meet his needs exactly. A good command of clear English is one of the most important qualifications, and of equal importance is the need that the engineer shall be qualified by experience as well as theoretical knowledge in the field which his specifications will cover. The language should be as definite and simple as possible, avoiding obscurities, or double meanings, or ambiguities of any sort. The engineer's state of mind and his intent cannot be too clearly expressed.

In general it is best to treat but one feature or requirement in each clause, and to dispose of it there completely. This tends to avoid confusion and misunderstandings. It is also an excellent practice to place the subject of the clause in the margin, as a heading or topic, and number the clauses consecutively. The majority of specifications include drawings of some description and these should be carefully named by title and number. It is always well to place a clause near the opening of the specification stating what drawings, maps, plans, etc., form a part of it.

In the case of very large or comprehensive work, it will be advisable to draw separate specifications for each unit or component part of the plant or equipment. These detail specifications can then be made a part of the general specification by inserting a clause or provision to that effect. This will save repetition and facilitate the work of drawing the complete specifications.

General Clauses

Assuming that the contract and the specification form a single complete instrument, the various clauses and provisions can be separated under the heads of general clauses and specific or technical clauses. The former relate to the business relations; the latter to the work to be done.

It is impossible to cover all the features which the general clauses should deal with, but it is possible to indicate in a general way the essential things to provide for. The following list of topics is not given for the purpose of being copied, but instead to show some of the things which should be included in a general case; and it is not necessarily complete. These general clauses vary greatly, of course, according to circumstances. They form naturally the more purely legal portion of a specification

Digitized by Google

and in every case of doubt a competent authority should be consulted.

1. Preamble stating the names of the contracting parties and their general intent.
2. Time of commencement of the work, rate of progress and date of completion.
3. The character of the methods and appliances to be used, and the grade of workmen to be employed.
4. Method of payment, times of settlement and basis thereof.
5. Preparation and checking of work estimates, in preparation for settlement.
6. Final settlement.
7. Powers of the engineer:—arbitrator in disputes; changes in the plans; inspection of the work.
8. Penalties or liquidated damages for failure to complete within specified time.
9. Unpaid claims against the contractor for labor and materials.
10. No claims for damages { Suspension of work. / Delays. / Unforseen difficulties.
11. Protection { Finished work. / Life and property. / Patent suits.
12. Removal of condemned material and cleaning up the work.
13. Inspections and tests of material.
14. Relations between two or more contractors.
15. Correction of faults.
16. Arbitration and settlement of disputes.
17. Contractor to place plant in operation.
18. Final inspections and tests.
19. Final delivery and acceptance of completed work.
20. Extras and claims therefor.
21. Definition of engineer and contractor.
22. Meaning of contract understood.
23. No waivers of legal rights.

These clauses relate to general construction work, but there are many forms of specifications in electrical engineering for which they are unsuited. There would be almost no end to the task of attempting to cover the whole field. In specific cases specifications for similar work should be consulted, if possible, and also the generally recognized authorities on engineering contracts. In the main the aim of the general clauses is to cover the entire business relations between the contracting parties, and every contingency of a business nature which is likely to arise.

Digitized by Google

Technical Clauses

The technical clauses cover the actual work or construction and as a rule go to make up the major portion of the specifiction. In their preparation only the most general rules can be laid down as a guide. The modern tendency is to make specifications more definite and exact, at the expense of brevity. There is probably a happy medium in this respect, however, and unnecessary length is a serious objection—for perfectly evident reasons. The general rules for guidance may be laid down about as follows:

1. Describe the work as a whole and in detail, in clear, concise and forceful language.
2. Treat but one thing at a time, and that completely.
3. Show the clear intent and state of mind. Resort to alternatives only as absolutely necessary, or when specifically intended.
4. Define all units carefully and definitely.
5. Avoid conflicting requirements and be careful to limit the requirements to those absolutely essential in securing the results desired.
6. When possible, make use of the standards and standardization rules of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers and the American Society of Civil Engineers.
7. Avoid specifying proprietary articles or materials as far as possible, unless definitely wanted. When public bids will be invited by a municipality, for example, proprietary articles, brands, makers names, etc., are prohibited.
8. Before drawing the specification, determine to what extent the contractor is to be made responsible for the final result.
9. Provide for inspections and tests of both material and workmanship at all essential stages of construction or manufacture.
10. Carefully state the methods of inspecting and testing to be used, and define all standards, relative or absolute, which will be employed.
11. Avoid any phrasing which will permit the use of inferior substitutes.
12. Bear in mind that quality is an important factor in cost; and unless the very best materials and workmanship are desired, regardless of cost, adopt fair commercial standards. Some preliminary inquiry and study of this matter may be advisable.
13. Keep in mind all statute and ordinance requirements in relation to buildings, plants, electric wiring, fire protection, etc.; also the rules of the underwriters.

These rules are exceedingly general in their nature, but very important. It is not possible to carry the subject to great lengths in an interesting manner, without concrete examples. The three illustrations next given were chosen largely because of their

Digitized by Google

brevity; it is not possible to take up a long or complicated specification, such as one for a complete power plant, in a comparatively short paper of this kind.

Examples of Specifications

The following specification for rubber insulated signal wire was adopted by the Railway Signal Association, during the present year.

Specification for Rubber Insulated Signal Wire for Current of 660 Volts or Less

Conductors.

1. Conductors must be of soft drawn, annealed copper wire having a conductivity of not less than ninety-eight (98) per cent of that of pure copper, Matthiessen's standard. Each wire forming a conductor must be continuous without weld, splice or joint throughout its length, must be uniform in cross section, free from flaws, scales and other imperfections and provided with a heavy uniform coating of tin.

Rubber Insulation.

2. The rubber insulation shall be made exclusively from pure Upriver, fine, dry, Para rubber, of best quality, which has not previously been used in a rubber compound, solid waxy hydrocarbons, suitable mineral matter and sulphur, properly and thoroughly vulcanized. Before being mixed with the other ingredients the rubber shall be thoroughly washed and dried.

3. The insulation must be homogeneous in character, tough, elastic, adhering strongly to and be placed concentrically around the wire.

Braiding.

4. The rubber insulation must be protected with one layer of closely woven cotton braiding at least one thirty-second (1-32) of an inch thick, saturated with a black insulating weatherproof compound that shall be neither injuriously affected by nor have injurious effect upon the braid at a temperature of 200 deg. Fahr.

Acceptance.

5. The product of those concerns only will be accepted who have satisfied the purchaser that the requirements of this specification will be complied with. The decision as to the quality of the wire furnished and the acceptance of the same shall be made by the purchaser.

Tests.

6. The manufacturer shall provide at his factory apparatus and other facilities needed for making the required physical and electrical tests. The manufacturer shall give free access to the place of manufacture and opportunity for inspecting and testing the product at all stages of manufacture to show that the required amount and quality of Para rubber and other ingredients are being used in the compound.

Digitized by Google

7. Tests shall be made from samples taken from any part of any coil and may also be made upon the finished product immediately after being delivered. If the requirements of this specification are not met the wire will be rejected and the manufacturer shall pay freight charges for return of such material.

8. At the option of the purchaser the wire, after being tested, shall not be shipped from the factory until an analysis of a sample has been made by a chemist chosen by the purchaser and the results of such analysis as interpreted by the purchaser, shall be sufficient ground for rejection should the wire or insulation not conform to the requirements of this specification.

Physical Test of Copper Conductors.

9. Each solid conductor must stand an elongation of twenty-five (25) per cent of its length in ten (10) inches before breaking and must be capable of being wrapped six (6) times about its diameter without showing signs of breakage.

Conductivity Test of Copper.

10. The conductivity of the copper shall be determined by measuring the resistance of a length of the wire and comparing with Matthiessen's standard of copper resistance.

Test of Tinning.

11. Samples of wire shall be thoroughly cleaned with alcohol and immersed in hydrochloric acid of specific gravity 1.088 for one (1) minute. They shall then be rinsed in clear water and immersed in a solution of sodium sulphide of specific gravity 1.142 for thirty-two (32) seconds and again washed. This operation shall be repeated three (3) times and if the sample does not become clearly blackened after the fourth immersion, the tinning shall be regarded as satisfactory.

12. The sodium sulphide solution must contain an excess of sulphur and should have sufficient strength to thoroughly blacken a piece of clean untinned copper wire in five (5) seconds.

Tests of Braiding.

13. A six (6) inch sample of wire with carefully paraffined ends shall be submerged in fresh water of a temperature of 70 deg. Fahr. for a period of twenty-four (24) hours. The difference in weight of the sample before and after submersion must not be more than ten (10) per cent of the weight of the sample before submersion less the weight of the copper and vulcanized rubber.

Physical Tests of Rubber Insulation.

14. A sample of the vulcanized rubber insulation not less than four (4) inches in length shall have marks placed upon it two (2) inches apart. The sample shall be stretched at the rate of three (3) inches per minute until the marks are six (6) inches apart and then at once released. One (1) minute after such release the marks shall not be over two and seven-sixteenths (2 7-16) inches apart. The sample shall then be stretched until the marks are nine (9) inches apart before breaking.

Digitized by Google

15. The tensile strength of the rubber insulation as shown by tests made on a carefully prepared sample shall be not less than one thousand (1000) pounds per square inch. The sample, for five (5) minutes before and as near as practicable during the test shall be maintained at a temperature of seventy (70) deg. Fahr.

16. The specific gravity of the rubber insulation shall not be less than 1.75.

Chemical Tests of Rubber Insulation.

17. The insulation shall show on analysis not less than thirty (30) nor more than thirty-three (33) per cent of pure Upriver fine dry Para rubber of best quality; not more than four (4) per cent of waxy hydrocarbons consisting of refined paraffine or pure ozokerite; not more than 0.7 per cent of free sulphur; not more than 2.5 per cent total sulphur; freedom from all foreign matter and the mineral matter shall be such as will not have a deleterious effect on the insulation.

Electrical Tests of Rubber Insulation.

18. The circular mills cross section, the thickness of the rubber insulation (measured at the thinnest point), the minimum insulation resistance in megohms per mile and the dielectric strength for the various sizes of wire shall conform to the following requirements:

Size B. & S. Gauge	Area in Circular Mils	Thickness of Insulation	Insulation Resistance Megohms Per Mile	Test Voltage Alternating Current
0	105,592	$\frac{1}{8}$″ wall	900	10,000
1	83,694	$\frac{1}{8}$″ "	1,100	10,000
2	66,373	$\frac{1}{8}$″ "	1,200	10,000
4	41,742	3-32″ "	1,100	9,000
6	26,250	3-32″ "	1,300	9,000
8	16,509	3-32″ "	1,600	9,000
9	13,090	5-64″ "	1,500	7,000
10	10,380	5-64″ "	1,600	7,000
12	6,530	5-64″ "	1,900	7,000
14	4,107	5-64″ "	2,100	7,000
16	2,583	1-16″ "	2,100	4,000
18	1,624	1-16″ "	2,400	4,000

19. The test for insulation resistance must be made upon all wire after at least twelve (12) hours submersion in water and while still immersed results be corrected to a water temperature of sixty (60) deg. Fahr. Tests must be made with the wire in coils, suitable for examination and before the application of braid or other covering with a well-insulated battery and galvanometer, with not less than one hundred (100) volts and readings must be taken after one minute's electrification. The test voltage must be appli d to the completed length of wire before the insulation test for a period of five (5) minutes, using alternating current from a generator and transformer of ample capacity.

Digitized by Google

Coils.

20. The wire shall be furnished in coils of the length named for the following sizes of wire:

B. & S. Gauge.	Length in Feet.
No. 14	2,000
No. 12	1,500
No. 10	1,500
No. 8	1,500
No. 6	1,000

21. Twenty (20) per cent of the coils will be accepted if five hundred (500) feet long or over, or of any length where a coil, submitted for inspection and testing has been cut to secure a sample for testing.

22. The inside diameter of a coil shall, unless otherwise specified, be not less than twenty (20) or more than twenty-two (22) inches.

Packing for Shipment.

23. The wire shall be shipped in reels or coils as directed by the Purchaser.

24. If shipped on reels they shall be amply strong and the wire shall be protected by lagging to prevent injury in transportation. A tag must be placed inside of the lagging and a stencil on the outside of each reel giving the weight, the length of each piece of wire, the size of the wire, the name of the Manufacturer and Purchaser's order or inspection number plainly marked.

25. If shipped in coils, each coils shall be securely bound with a layer of heavy wrapping paper and with an outside wrapping of burlap, with each turn of burlap overlapping the other one-half ($\frac{1}{2}$) its width.

26. Each coil shall have the weight, length and size of wire, the name of maker and purchaser's order or inspection number plainly and indelibly marked on two (2) strong tags. One of these tags shall be attached to the coil inside the burlap and the other shall be attached to the coil outside the burlap.

The next example is that of a small dynamotor for operating telegraph lines. This machine has a double-wound armature with two commutators, rotating in the same magnetic field. The voltage ratio is fixed, except as it can be varied by a rheostat in the primary armature circuit. The secondary delivers continuous current at constant voltage. This is a good example of a carefully drawn specification, intended to prevent the tender of inferior machines.

SPECIFICATION FOR A 25-WATT DYNAMOTOR

The apparatus desired under these specifications must be of the quality herein specified and the mechanical and electrical properties must be those called for herein.

The purchaser shall have the right to make such tests of the machine as he desires, and a machine not satisfactory in output, effi-

Digitized by Google

ciency, workmanship or design must be corrected at once by the manufacturer or the machine will be rejected.

Type.

The machine shall furnish direct current as hereinafter specified and shall operate on a constant potential direct current circuit.

The machine shall have a single armature with the primary commutator at one end and the secondary commutator at the other. The ends shall be plainly designated, by being stamped P. and S. respectively. The machine shall be self-contained on a single base so arranged that it may be secured to a foundation.

Output.

The machine shall be capable of delivering continuously at the specified voltage an output of twenty-five thousandths (0.025) of a kilowatt, at a speed not greater than eighteen hundred (1800) rev. per min.

Voltage.

The secondary voltage, at full load, shall be either sixty (60) or one hundred (100) volts as specified.

The primary voltage shall be as specified.

Regulation.

At constant primary rated voltage the ratio of the maximum difference of the secondary terminal voltage from the rated full load voltage, to the secondary full load voltage, shall not exceed fifteen (15) per cent.

At constant primary rated voltage the ratio of the maximum difference of speed from the rated full load speed, to the rated full load speed, shall not exceed ten (10) per cent.

Efficiency.

The ratio of the electrical output to the electrical input at full load shall not be less than forty (40) per cent.

At constant primary rated voltage the electrical input with no electrical output shall not exceed thirty-three (33) watts.

Heating.

At continuous rated full load the rise of temperature of the various parts of the machine shall not exceed the following values:

Field and armature, by resistance, fifty deg. cent. (50° cent.); by thermometer, forty-five deg. cent. (45° cent.).

Commutator and brushes, by thermometer, fifty-five deg. cent. (55° cent.).

Bearings and other parts of the machine, by thermometer, forty deg. cent. (40° cent.).

Overload.

The dynamotor shall be capable of running for two (2) hours at one hundred (100) per cent overload without injury to any part.

Dielectric Strength.

The insulation between the windings and between either winding and the frame shall not break down when submitted to a mean effective difference of potential of one thousand (1000) volts alternating electromotive force continuously applied for one minute.

Digitized by Google

Commutation.

At all loads not exceeding the full rated load, and with no change in the position of the brushes or brush holders, the machine shall operate without sparking.

The brushes and commutators shall perform their functions without undue noise.

Electrical Balance.

If the dynamotor is to be operated from a storage battery used for common battery telephone circuits, its operation shall be such as to ensure, at any normal condition of speed and load, no disturbing noise in telephone circuits connected across the terminals of the storage battery.

Each commutator shall have such a number of segments that the product of the rated full load speed and the number of segments shall be not less than 50,000.

Mechanical Balance.

The mechanical balance of the rotating parts shall be such as to cause neither vibration nor noise at any load not exceeding the full rated load.

Bearings.

The bearings shall be self-oiling, self-aligning and provided with means for drawing off the working supply of lubricant. The self-oiling mechanism shall be normally closed to the entrance of foreign matter but shall be readily accessible for inspection.

Brushes.

The brushes shall be of carbon and shall be copper plated.

The current density in the brushes shall not exceed twenty (20) amperes per square inch.

Brush Holders.

All brush holders shall be of adequate strength and shall permit, without the use of tools of any sort, adjustment of the pressure of the brushes on the commutator, of the brushes in the holders, and of the brushes circumferentially about the commutator.

Leads and Wiring.

All leads shall be flexible, insulated and readily accessible.

All internal wiring shall be complete to the terminals.

Terminals.

Terminals shall be substantial, accessible, and arranged to receive the ends of the power leads.

Rheostat.

A fire proof starting rheostat (capable of also fulfilling the functions of a single-pole main switch) shall be furnished, mounted, and wired in a safe and accessible position on the machine. The "On" and "Off" positions of the rheostat shall be plainly marked.

Material.

All material and finish shall be of the best commercial grades.

Finish.

The various parts of the machine shall present a clean, smooth and finished appearance. All unfinished surfaces shall be filled and

Digitized by Google

rubbed down until they present a smooth, even surface, and then painted as specified by the purchaser. All polished surfaces shall be free from tool marks.

Standards and Tests.

All standards and methods of testing shall be in accordance with the Report of the Committee on Standardization of the American Institute of Electrical Engineers of June 1907 except where otherwise specified.

The third and last example is that of standard underground telephone cable, up to 180 pairs of No. 19 B. & S. gauge conductors or 400 pairs of No. 22 gauge, with dry paper insulation. It is notable that the kind of insulation is nowhere mentioned in the specification, but it is impossible to secure the low values of electrostatic capacity with any of the other insulating materials in ordinary use.

SPECIFICATIONS FOR NO. 19 AND NO. 22 B. & S. GAUGE TELEPHONE CABLE

The materials used in the manufacture of the cables must be of the quality herein specified, and the electrical properties and the methods of manufacture must be those herein called for. The quality of the materials used and the electrical properties of the cables must be determined by the manufacturer before the cables are delivered.

The purchaser is to have the right to make such tests of the quality of the materials used, and of the electrical properties of the finished cables, as he may desire. The inspector for the purchaser is to have the power to reject the cables should the quality of the materials used, or the electrical properties of the cables, fall below the requirements herein specified.

The manufacturer shall guarantee that for one year from the time the cables are placed, spliced and connected to terminals, the electrostatic capacity and the resistance of the conductors shall not have increased, nor the insulation resistance have decreased, beyond the limits herein specified, due to defective material or manufacture. The manufacturer shall, however, not be responsible for the failure of cables brought about by injuries to the sheath or conductors due to causes beyond his control.

General.

These specifications apply to cables of 180 pairs and less with No. 19 Brown and Sharpe gauge conductors, and to cables of 400 pairs and less with No. 22 Brown and Sharpe gauge conductors.

Conductors.

Each conductor shall be of soft copper and of such conductivity as will ensure, at all seasons of the year, a conductor resistance of not more than forty-seven (47) ohms for each mile of cable with No. 19 gauge conductors, nor more than ninety-five (95) ohms for each mile of cable with No. 22 gauge conductors.

Digitized by Google

Core.

The conductors shall be insulated, twisted in pairs, the length of the twist not to exceed three (3) inches, and formed into a cylindrical core arranged in reversed layers. The ends of each length of cable shall be filled with an insulating material which shall seal the cable for a distance of at least two (2) feet from each end.

Sheath.

The core shall be enclosed in a sheath of uniform thickness composed of lead and tin, the amount of tin to be not less than three (3) per cent. This sheath shall be formed around the core and shall be free from holes or other defects.

For cables with No. 19 gauge conductors, the thickness of the sheath shall be as follows:

For cables of 100 pairs and over, not less than one eighth (⅛) of an inch; for cables of from 50 to 100 pairs, not less than three thirty-seconds (3/32) of an inch; for cables of less than 50 pairs, not less than one twelfth (1/12) of an inch.

For cables with No. 22 gauge conductors, the thickness of the sheath shall be as follows:

For cables of 200 pairs and over, not less than one eighth (⅛) of an inch; for cables of from 100 to 200 pairs, not less than three thirty-seconds (3/32) of an inch; for cables of less than 100 pairs, not less than one twelfth (1/12) of an inch.

Electrostatic Capacity.

At any season of the year, the average mutual electrostatic capacity between one wire of a pair and its mate (the remainder of the conductors and the sheath being grounded) shall not exceed 0.054 of a microfarad per mile of cable with No. 19 gauge conductors, nor 0.069 of a microfarad per mile of cable with No. 22 gauge conductors.

The mutual electrostatic capacity of any pair of the cable so measured shall not exceed 0.060 of a microfarad per mile of cable with No. 19 gauge conductors, nor 0.078 of a microfarad per mile of cable with No. 22 gauge conductors.

These figures apply only to the cable, and proper allowance shall be made for the rubber-covered wire used at the terminals.

Insulation Resistance.

Each wire shall show an insulation resistance of not less than five hundred (500) megohms per mile of cable, each wire being measured against all the rest and the sheath grounded.

Note.

The tests for insulation resistance may be made with an electromotive force not exceeding five hundred and fifty (550) volts.

As a measure of safety, when more than two hundred (200) volts are employed in such tests, a resistance of one hundred thousand (100,000) ohms should be included in the circuit with the source of electromotive force and the conductors of the cable.

In all of the examples given, the general clauses are absent, that is to say, the business relations of the contracting parties,

Digitized by Google

in relation to price, shipment, delivery, etc. The latter vary so greatly that mere blank forms could be presented, in any case.

In concluding the paper, attention is drawn to the fact that principles have been emphasized rather than practice; of practice it can best be said that it changes from year to year, while principles do not—a most fortunate truth for us all.

Bibliography

1. " Engineering and Architectural Jurisprudence," by John C. Wait, 1898.

2. " Law of Operations Preliminary to Construction in Engineering and Architecture," by John C. Wait, 1900

3. " The Law of Contracts," by John C. Wait, 1901.

4. " Engineering Contracts and Specifications," by J. B. Johnson, 1902.

5. " Specifications and Contracts," by J. A. L. Waddell and J. C. Wait, 1908.

6. " Law and Business of Engineering and Contracting," by Charles E. Fowler, 1909.

7. " Contracts in Engineering," by James I. Tucker, 1910.

Digitized by Google

Digitized by Google

UNIV. OF MINNESOTA LIBRARY COL. OF ENGINEERING

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 10

October, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

October Meeting A. I. E. E., New York, October 13, 1911 - - 277
Future Section Meetings - - - - - - 277
Dressing Room Facilities in Engineers' Building - - - - 277
President de Ferranti in the United States - - - - 277
Applications for Election - - - - - - 278
Annual Meeting of Chemical Engineers - - - - - 278
Past Section Meetings - - - - - - - 278
Personal - - - - - - - - - 279
Obituary - - - - - - - - - 280
Library Accessions - - - - - - - 280

Section II. Papers, Discussions, and Reports

A Theory of Commutation and Its Application to Interpole Machines. By B. G. Lamme, New York, October 13, 1911 - - - - 2049
Discussion on "Some Recent Developments in Railway Telephony," Los Angeles, Cal., April 27, 1911 - - - - - - 2095
Discussion on "Cisoidal Oscillations," Los Angeles, April 25, 1911 - 2107
Discussion on "New Automatic Telephone Equipment," and "The Semi-Automatic Method of Handling Telephone Traffic," Los Angeles, April 26, 1911 - - - - - - - 2111
Discussion on "Electricity in the Lumber Industry," Los Angeles, April 27, 1911 - - - - - - - - 2142
Discussion on "Continuity of Service in Transmission Systems," Los Angeles, Cal., April 27, 1911 - - - - - - - 2145
Discussion on "The Refining of Iron and Steel by Induction Type Furnaces," Los Angeles, Cal., April 25, 1911 - - - - 2153
Discussion on "Elevator Control," Chicago, June 28, 1911 - - 2158
Discussion on "Choice of Rotor Diameter and Performance of Polyphase Induction Motors," Chicago, June 30, 1911 - - - - 2160
Discussion on "Commercial Loading of Telephone Circuits in the Bell System," Chicago, June 28, 1911 - - - - - 2168
Discussion on "The High Efficiency Suspension Insulator," Chicago, June 30, 1911 - - - - - - - 2177
Discussion on "Problems in Telephone Traffic Engineering," Chicago, June 28, 1911 - - - - - - - 2184
Discussion on "The Economical Design of Direct-Current Electromagnets," Chicago, June 30, 1911 - - - - - 2189
Discussion on "Telegraph Transmission," Chicago, June 28, 1911 - 2193
Discussion on "The Use of Power Limiting Reactances with Large Turbo-Alternators," "Some Recent Tests of Oil Circuit Breakers," and "Development of the Modern Central Station," Chicago, June 27, 1911 - - - - - - - - 2196

Index to Advertisements - - - - - - - iii

Copyright 1911, by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

JUST PUBLISHED

Electric Traction and Transmission Engineering

By Samuel Sheldon, A.M., Ph.D., D.Sc.

Professor of Physics and Electrical Engineering at the Polytechnic Institute of Brooklyn and Past-President of the American Institute of Electrical Engineers

AND

Erich Hausmann, E.E., M.S.

Instructor in Physics and Electrical Engineering at the Polytechnic Institute of Brooklyn and Associate of the American Institute of Electrical Engineers

¶ The essential facts to be considered in determining the final elements of a complete electric system are here carefully presented so as to give a perspective view of the installation from the cars to the power station. The nature and sequence of the various problems involved are indicated, and methods for their solution are suggested and illustrated.

CONTENTS

¶ Determination of the Number and Size of Cars for an Urban Road. Tractive Effort Required for Car Propulsion. Types and Performance Curves of Motors. Speed Curves. Railway Motor Control. Emergency. Consumption. The Distributing System. Substations. Transmission Lines. Steam and Hydraulic Power Stations.

317 Pages 101 Illustrations 5½x8¾ Net $2.50

Second Edition—Greatly Enlarged

Direct and Alternating Current Manual

By Frederick Bedell, Ph.D.

Professor of Applied Electricity in Cornell University

ASSISTED BY

Clarence A. Pierce, Ph.D.

CONTENTS

¶ Direct Current Generators. Direct Current Motors. Synchronous Alternators. Single-Phase Currents. Transformers. Polyphase Currents. Phase Changers. Potential Regulators. *Induction Motors. *Induction Generators. *Frequency Changers. *Synchronous Motors. *Synchronous Converters. *Wave Analysis. *Special Problems.

*New material in the second edition

360 Pages Illustrated 6x8¾ Net $2.00

D. VAN NOSTRAND COMPANY

Publishers and Booksellers

23 Murray and 27 Warren Streets - - - New York

Digitized by Google

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX October, 1911 No. 10

October Meeting, A. I. E. E., New York, October 13, 1911

The two hundred and sixty-fourth meeting of the American Institute of Electrical Engineers, marking the opening of the season of 1911–1912, will be held in the Engineers' Building, 33 West 39th Street, New York City, on Friday, October 13, 1911, at 8:15 p.m. A paper entitled "A Theory of Commutation and Its Application to Interpole Machines" will be presented by Mr. B. G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.

Future Section Meetings

WASHINGTON, D. C.

The first meeting of the Washington Section for this season will be held at 8 p.m. on Tuesday, October 10, 1911. The place of meeting will be the Telephone Building, and the principal address will be delivered by an out of town engineer. *H. B. Stabler, Secretary, 722 12th Street, N. W., Washington, D. C.*

Dressing Room Facilities in Engineers' Building

The attention of Institute members is directed to additional facilities, in the form of several dressing booths, which have been installed in the mezzanine lavatory of the Engineers' Building, 33 West 39th Street. The booths are equipped with all the necessary fixtures and will be at the service of members attending meetings or other functions. Out of town members particularly will appreciate this innovation, since it will enable those leaving the city the same night to save time, hotel expenses, and the inconvenience of looking about for temporary quarters. The check-room for coats, hats, etc., is on the second floor. Any of the attendants in the building will direct members desiring to avail themselves of the use of the dressing booths.

President de Ferranti in the United States

Mr. S. Z. de Ferranti, President of the Institution of Electrical Engineers, of Great Britain, accompanied by Mrs. de Ferranti, is visiting this country. He arrived in New York on September 8, and with several other prominent English engineers has inspected some of the important electrical developments in New York, Chicago, and elsewhere. On Friday, September 29, a luncheon was given at the Engineers' Club, New York, in honor of President de Ferranti by the officers and past-presidents of the Institute. The foreign visitors who were guests of the Institute upon this occasion were, Messrs. S. Z. de Ferranti, H. A. Couves, H. R. Harper, Chas. H. Merz, Vincent Raven, Edward Thompson, and Arthur Wright. Nine past-presidents and fifteen officers of the Institute were also present. Mr. H. W. Buck, chairman of the luncheon committee, acted as toast-master, and brief addresses were also made by Messrs. S. Z. de Ferranti, C. H. Merz, Arthur Wright, B. J. Arnold, J. J. Carty, J. W. Lieb, Jr., C. F. Scott and H. G. Stott. The occa-

Digitized by Google

sion was a very enjoyable one to all present and will tend to strengthen the cordial feeling already existing between the Institution of Electrical Engineers of Great Britain and the American Institute of Electrical Engineers.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before October 25, 1911.

10668 Anderson, E. R., Pittsfield, Mass.
10669 Bisbee, D. W., Nacozari, Son., Mex.
10670 Hansell,C.E., W. La Fayette, Ind.
10671 Johansson, K. W., Pittsburgh, Pa
10672 Lessig, J. F., Wilkes-Barre, Pa.
10673 Yapp, L. C., Fort Wayne, Ind.
10674 Case, C. E., Chicago, Ill.
10675 Freeman, W. E., Lexington, Ky.
10676 Hall, W. A., Seattle, Wash.
10677 Kornfeld,F.H.,Schenectady,N.Y.
10678 McKeen, W. J., Seattle, Wash.
10679 Mereen, J. D., Marshfield, Ore.
10680 Smith, T. C., Seattle, Wash.
10681 Ennis, W. H., New Orleans, La.
10682 Hobcroft, E. C., New York City.
10683 King, E. T., Lakewood, Ohio.
10684 Milton, R. H., Greensboro, N. C.
10685 Pearce, S. H., Ruskin, B. C.
10686 Silvia, G. F., Albany, N. Y.
10687 Alexandre, W., New York City.
10688 Benson, M. B., Duluth, Minn.
10689 Hahn, W., Oakfield, N. Y.
10690 Haynes, A. R., Tacoma, Wash.
10691 Mills, J., New York City.
10692 Webster, G. C., Cleveland, Ohio.
10693 Evans, G. M., New York City.
10694 Simpson, T. W., Chicago, Ill.
10695 Andrews, A. S., Lethbridge, Alta., Can.
10696 Schulz, A. C., Bridgeport, Conn.
10697 Sills, G. F., Toronto, Ont.
10698 Boyden, D. S., Boston, Mass.
10699 Edwards, C. O., Plains, Mont.
10700 Pawlett, L. M., Bridgeport, Conn
10701 Stockbridge, W. A., Fort Wayne, Ind.
10702 Bell, J. H., Newark, N. J.
10703 Burdette, H. E., Atlanta, Ga.
10704 Byerts, W. E., Davenport, Iowa.
10705 Clark, A. T., Baltimore, Md.
10706 Eriksson, N. E., Toronto, Ont.
10707 Hardley, J. E., Auckland, N. Z.
10708 Havill, O. A., New York City.
10709 Howard, F. P., Baltimore, Md.
10710 King, J. E., Wilkinsburg, Pa.
10711 Lofvengren, N. W., Toronto,Ont.
10712 Motomura, S., Tokyo, Japan.
10717 Ashley, E. E., Jr., New York City
10718 Miltenberger,A. L., St.Louis, Mo.
10719 Wright, J. L., Seattle, Wash.

Total 48.

Annual Meeting of Chemical Engineers

The fourth annual meeting of the American Institute of Chemical Engineers will be held in Washington, D. C., on Wednesday, Thursday and Friday, December 20, 21 and 22. A number of important papers will be presented on the subject of patents, and the manufacture and testing of explosives, as well as on other chemical engineering subjects. One day will probably be devoted to visits to the technical chemical engineering plants in Baltimore and vicinity. Visits to laboratories and other points of interest in Washington will also be arranged for.

Past Section Meetings

Cleveland

The first meeting of the Cleveland Section for the season of 1911–1912 was held in the library of the Chamber of Commerce on September 18, with Chairman B. A. Stowe presiding. The invitation from Mr. W. M. Faber, steam engineer, to the members of the Cleveland Section to visit the central furnaces and Newburg plants of the American Steel and Wire Company, was accepted, and arrangements were made for a joint inspection trip of the Section with the Cleveland Engineering Society on September 22. The plans of the Section for the coming year were

Digitized by Google

discussed, and a number of committees were appointed.

Fort Wayne

The Fort Wayne Section held its first meeting this season on September 14, in the lecture room of the Fort Wayne Electric Works. The chief feature of the program was an illustrated lecture by A. A. Severa, sales manager of the works, on "Electrical Development in the West."

Milwaukee

The annual meeting of the Milwaukee Section was held in the Plankington House, Milwaukee, on June 14, 1911. Ninety-six members were present. The following officers were elected for the ensuing administrative year: Chairman, F. A. Vaughan; secretary, L. L. Tatum. No technical papers were presented. The meeting was held in conjunction with the annual meeting of the Engineers' Society of Milwaukee.

Pittsburgh

The Pittsburgh Section held its opening meeting for this season in the rooms of the Engineering Society of Western Pennsylvania, Pittsburgh, on September 12, 1911. The annual report of the secretary and treasurer was presented, after which the following officers were elected: Chairman, K. C. Randall; secretary and treasurer, E. L. Farrar; executive committee, S. P. Grace, E. P. Vankirk, E. Friedlander, R. W. Atkinson; R. V. Bingay, R. S. Feicht. Mr. H. N. Muller, who represented the Pittsburgh Section at the Chicago Convention, presented his report, which was followed by a talk by Mr. Paul M. Lincoln in regard to the work of the Sections Committee, of which Mr. Lincoln is chairman.

Messrs. W. M. McConahey, Paul M. Lincoln, C. Fortescue, S. M. Farnsworth and H. C. Soule then discussed the papers presented at the Chicago Convention under the auspices of the high tension transmission committee. Seventy-three members were present at the meeting.

Toledo

The annual meeting of the Toledo Section was held in the Y. M. C. A. parlors on June 2, 1911. The following officers were elected for the year beginning October 1, 1911: Chairman, George E. Kirk; vice-chairman, John Gilmartin; executive committee, George E. Kirk, John Gilmartin, Max Neuber, M. W. Hansen, W. A. Hill. The election of officers was followed by a discussion by Messrs. Hill, Hansen and Neuber, on the arcing of motors.

The Section held its first meeting for the season in the Y. M. C. A. parlors on September 1. Mr. John Gilmartin opened a discussion on circuit breaker fuses and oil switches. Others taking part in the discussion were Messrs. Kirk, Hill, Grah, Nickels, Horan, Hansen, and Neuber. It was planned to have a dinner with five minute talks by each member during the latter part of September.

Personal

Mr. Robert N. Davidson was married on August 30 to Miss Ada Emogene Hutchins, of Fennville, Michigan. Mr. and Mrs. Davidson will be at home at Thompson, Nevada, after November first.

Mr. John Engler, of the Telefunken Wireless Telegraph Company of the United States, left for London and Berlin on the steamer George Washington on September 16, to remain abroad probably for about a year.

Mr. A. D. Du Bois, who for the last three years has been instructor in Sibley College, Cornell University, has resigned to become assistant professor of electrical engineering at Purdue University.

Mr. Arthur C. Hobble has accepted a position as electrical engineer with the Mexican Northern Power Company in connection with the 55,000 h.p., 110,000-volt Conchos River

Digitized by Google

development near Chihuahua in northern Mexico.

MR. H. F. WAY has resigned his position as assistant engineer with the Pacific Power and Light Company, North Yakima, Washington, and is now associated with the construction department of the Olympic Power Company,, Port Angeles, Wash.

MR. GUSTAF HOLMGREN, who for about 10 years has been chief in the alternating-current generator department of the Almanna Svenska Elektrisha, A.B., of Westeras, Sweden, has been appointed chief electrical engineer of A. B. de Lavals Angturbin of Stockholm, Sweden.

MR. R. H. ELLIOTT, until recently with the General Electric Company at Pittsfield, Mass., as transformer engineer, is now located at Chambersburg, Pa., as first assistant engineer on the gravity water and sanitary sewer system which the city is now installing.

MR. C. A. SOANS, who for the past two years has been associated with the Belden Manufacturing Company of Chicago, in the development of their magnet wire, is now connected with the Bijur Motor Lighting Company, of New York, manufacturers of direct-current generators for lighting of automobiles and motor boats.

Obituary

MR. RICHARD A. TURNER, of Richard A. Turner and Company, electrical engineers and contractors, Springfield, Mass., died on June 2, 1911, after an operation for appendicitis. Mr. Turner was born in Willimantic, Conn., on February 19, 1875, and received his education in the Willimantic High School and Lehigh University. From 1897 to 1905 he was in the employ of a number of large electrical contracting concerns. In 1906 he entered the employ of Fred T. Ley and Company, of Springfield, Mass., as superintendent of construction, where he had responsible charge of a number of important installations of electrical power in mills. He subsequently organized the firm of Richard A. Turner and Company. Mr. Turner became an Associate of the Institute on August 14, 1908.

Library Accessions

The following accessions have been made to the library of the Institute since the last acknowledgment.

Address of Sir Robert A. Hadfield, July 1, 1911. N.p. n.d. (Gift of Sir Robert A. Hadfield.)

Addresses made at banquet given by H. M. Byllesby at Chicago Club, June 29, 1911. N.p. n.d. (Gift of author.)

American Institute of Electrical Engineers TRANSACTIONS. Vol. 29, pts. 1–2. New York, 1911.

American Society of Heating and Ventilating Engineers Transactions. Vol. 15, 1909. New York, 1909. (Gift of American Society of Heating and Ventilating Engineers.)

Electrical Trades Directory and Handbook, 1911. London, 1911. (Purchase.)

Das Elektrische Kabel. Ed. 2. By P. C. Baur, Berlin, 1910. (Purchase.)

Flicker on Fixed and Rotating Targets. By A. E. Kennelly, G. R. Carter and E. A. Healey. N.p. n.d. (Gift of A. E. Kennelly.)

Franchises on Electrical Corporations in Greater New York. A report submitted to the Public Service Commission for the First District. By M. R. Maltbie. New York, 1911. (Exchange.)

Die Gleichstrommaschine. Ed. 2, Vols. 1–2. By E. Arnold, Berlin, 1907. (Purchase.)

Government Contracts. The decision of the Boston Dry Dock Case. (Reprinted from Engineering Record. March, 11, 1911.) Washington, 1911. (Gift of Messrs. King & King.)

Digitized by Google

Imperial College of Science and Technology and City and Guilds of London Institute. Calendar of the Imperial College (Engineering), Part IV. Prospectus of the City and Guilds (Engineering) College. July, 1911. London, 1911. (Gift of Imperial College.)

Institution of Mechanical Engineers. Proceedings, 1910, parts 3–4. Westminster, 1910. (Exchange.)

Lewis Institute, Bulletin, July, 1911. Chicago, 1911. (Gift of Lewis Institute.)

McGraw Electric Railway Manual, 1911. New York, 1911. (Gift of McGraw Publishing Co.)

National Board of Fire Underwriters. Rules and Requirements for the construction and installation of Centrifugal Fire Pumps as recommended by the National Fire Protection Association. 1911. (Gift of National Fire Protection Association.)

——Use of Municipal Fire alarm systems. 1911. (Gift of National Fire Protection Association.)

——Use of Signaling systems used for the transmission of signals affecting the fire hazard. 1911. (Gift of National Fire Protection Association.)

National Fire Protection Association. Year Book, 1911. Boston, 1911. (Gift of National Fire Protection Association.)

New and Direct Process of Producing Alternating Current Vector Diagrams Experimentally. (Reprint from *Electrical World*, March 30, 1911.) By A. E. Kennelly, H. G. Crane and J. W. Davis n.p. n.d. (Gift of A. E. Kennelly.)

New England Water Works Association. Index to Transactions 1883–1885, Journal Vols. 1–7 n.p. n.d. (Gift of New England Water Works Association.)

——Transactions 1883, 1885, v. p. 1883, 1886. (Gift of New England Water Works Association.)

——Journal. Vol. 1, Nos. 1–3; Vol. 2, Nos. 1, 3–4; Vol. 3; Vol. 4, Nos. 2–4; Vols. 5–6; Vol. 7, Nos. 2–4; Vols. 8–14; Vol. 15, Nos. 1–5; Vols. 16–21. v.p. 1886–1907. (Purchase.)

New York State Department of Labor. Annual Report of the Bureau of Labor Statistics. Vols. I and II, 1909. Albany, 1910, 1911. (Gift of New York State Department of Labor.)

——Annual Report of the Commissioner of Labor 10th, 1910. Albany, 1911. (Gift of the New York State Department of Labor.)

New York State Public Service Commission for the First District. Proceedings. Vol 4, 1909. N.p. 1909. (Exchange.)

Nouvelle Industrie des Lampes électriques à Filaments Metalliques. By Charles Mourlon. Bruxelles, 1911. (Gift of author.)

Ontario Hydro-Electric Power Commission. Annual Reports 1–2, 1909. Toronto, 1910. (Gift of Hydro-electric Power Commission of Ontario.)

Oesterreichischer Betonverein. Bericht uber die III Ordentliche Hauptversammlung Wien, March 8, 1911. Wien, 1911. (Gift of Osterreichischer Betonverein.)

Peabody College for Teachers. Alumni Reunion. Register of Students, 1911. Nashville, 1911. (Gift of Peabody College for Teachers.)

Poor's Manual of Railroads, 1891, 1897, 1903. New York, 1891, 1897, 1903. (Purchase.)

Profession of Illuminating Engineering. By A. E. Kennelly n.p. n.d. (Gift of author.)

Railroad Signal Dictionary. By B. B. Adams and Rodney Hitt. New York, 1908. (Purchase.)

Report on the Telephone situation in the City of Chicago, 1907. Chicago, 1907. (Donor unknown.)

Rules and Regulations Governing Acceptance Tests of Direct Current and Single Phase Induction Watt-

Digitized by Google

hour Meters. Adopted June 21, 1911. (Bulletin E-M-1 State of New York Public Service Commission Second District. (Albany, 1911.) (Gift of State of N. Y. Public Service Commission—Second District.)

Die Spinnerei in technologischer Darstellung. By G. Rohn. Berlin, 1910. (Purchase.)

Syndicat Professionnel des Usines D'-Electricite Annuaire, 1911. Lille, 1911. (Gift of Syndicat Professionnel des Usines D'Electricite.)

Tests of pumping engine (No. 5) at the Zwaartkopjes pumping station of the Rand Water Board .By J. Orr. (Reprint Transvaal Institute of Mechanical Engineers.) (Gift of Transvaal Institute of Mechanical Engineers.)

U. S. Department of Agriculture, Yearbook. 1910. Washington, 1911. (Gift of Department of Agriculture.

Die Wechselstromtechnik. Ed. 2, Vols. 1–2. By E. Arnold. Berlin, 1910. (Purchase.)

Gift of Mr. Edward D. Adams

Through the kind efforts of Mr. Adams, the library is in receipt of a complete set of the published results of all experiments and tests made at the Physikalisch-Technischen Reichsanstalt at Berlin, including not only the large volumes of the Wissenschaftliche Abhandlungen but several hundred separates from technical periodicals containing the publications thus issued. The list accompanying the gift covers thirty six pages of cap paper, closely typewritten.

W.P.C.

Trade Catalogues

Allgemeine Elektricitatsgesellschaft. Berlin. Mine hoist safety devices. 94 pp.

Bell Electric Motor Co., Garwood, N. J. Bell High Efficiency Single Phase Motors. 16 pp.

Central Electric Co., Chicago, Ill. August, 1911 price list of electrical supplies. 88 pp.

Crocker-Wheeler Co., Ampere, N. J. Bulletin Index for live bulletins. 1 pp.

——Motor drive for printing machinery 16 pp.

——Bull. No. 136—Electric hoisting machinery. 6 pp.

Edison Storage Battery Co., Orange, N. J. Edison storage battery for ignition and lighting. 5 pp.

——Edison Storage Battery in Marine Service. 5 pp.

——Description of the Edison Storage Battery. 5 pp.

——The 1910 Edison Storage Battery, by Walter E. Holland. 26 pp.

——Useful Information About the Edison Storage Battery. 24 pp.

——The Edison Storage Battery and Its Application. 48 pp.

Emerson Electric Mfg. Co., St. Louis, Mo. Bull. No. 3142—Single phase induction motors. 16 pp.

——Bull. No. 3709—Electric buffing lathes. 4 pp.

General Electric Co., Schenectady, N. Y. Index to bulletins, May, 1911. 8 pp.

——Bull. No. 4802—Type "H" Transformer. 16 pp.

——Bull. No. 4818—Couplings. 9 pp.

——Bull. No. 4819—Alternating current switchboard panels with oil switches on panel. 42 pp.

——Bull. No. 4825—Switchboard instruments. 10 pp.

——Bull. No. 4827—Air flow meter. 10 pp.

——Bull. No. 4828—Aluminum lightning arresters for alternating current circuits. 27 pp.

——Bull. No. 4829—Electric Locomotives for Industrial Railways. 17 pp.

——Bull. No. 4831—Oil break switches for manhole service. 3 pp.

——Bull. No. 4832—Commutating Pole Generators. 6 pp.

——Bull. No. 4833—Electrically operated gold dredges. 7 pp.

——Bull. No. 4834—Electrical equipment of the Detroit river tunnel. 24 pp.

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL. DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **ACTING SECRETARY.**

GEORGE A. HAMILTON. FREDERICK L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH WAINWRIGHT POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

HORACE FIELD PARSHALL,
Salisbury House, London Wall, E. C., London.

L.A. HERDT, McGill University, Montreal, Que.

WILLIAM G. T. GOODMAN,
Adelaide, South Australia.

ROBERT JULIAN SCOTT,
Christ Church, New Zealand.

HENRY GRAFTIO, St. Petersburg, Russia.

Digitized by Google

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
FREDERICK L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
ALEXANDER S. LANGSDORF, St. Louis, Mo.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
FRED S. HUNTING, Fort Wayne, Ind.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman, 165 Broadway, New York.
EDWIN BRITTON KATTE, Vice-Chairman, New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
GEORGE GIBBS, New York.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

ALEXANDER S. LANGSDORF, Chairman, Washington University, St. Louis, Mo.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
JOHN PRICE JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman, General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman, 139 Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill.
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman, Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio.
ROBERT BELDEN TREAT, Ampere, N. J.
R. TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York.

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman, Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman, 43 Exchange Place, New York.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.
PHILIP TORCHIO, New York.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman, 600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

PUBLIC POLICY COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
HAROLD W. BUCK, New York.
JOHN J. CARTY, New York.
JOHN H. FINNEY, Washington, D. C.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman,
2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES WATERMAN STONE, New York.
CALVERT TOWNLEY, New York.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman,
29 West 39th St., New York.
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman,
52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President.
90 West St., New York.
ARTHUR E. KENNELLY, Secretary,
Harvard University, Cambridge, Mass.
Other members of this committee to be appointed later.

CODE OF ETHICS COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.
FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.
ELIHU THOMSON, Chairman,
Swampscott, Mass.
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913
COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.
WILLIAM S. BARSTOW, New York.
ROBERT B. OWENS, Philadelphia, Pa.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.
LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, New York.

Term expires July 31, 1912.
PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.
GANO DUNN, President, Ampere, N. J.
FREDERICK L. HUTCHINSON, Acting Sec.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New York.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, Pittsburgh, Pa.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	H. P. Wood.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	William L. Hooper.	G. A. Rodenbaeck, 84 State St , Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor, Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	K. C. Randall.	E. L Farrar, G. E. Co , Oliver Bldg , Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. B. Charters.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, Wagner Electric Mfg. Co., St. Louis, Mo.
Toledo.....June 3, '07	George E Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto.....Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana.....Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C...Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas.....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland.....Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College.....Feb. 11, '10	D. E. Byerley.	A. A. Catlin, 626 So. Meldrum St., Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute.....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oregon State Agr. Col Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan. 26. '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst. Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

Digitized by Google

A paper to be presented at the 264th meeting of the American Institute of Electrical Engineers, New York, October 13, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

A THEORY OF COMMUTATION AND ITS APPLICATION TO INTERPOLE MACHINES

BY B. G. LAMME

In the usual theory of commutation it is considered that, when the current in a coil is commutated or reversed, the local magnetic flux due to the current reverses also, and in so doing sets up an e.m.f. in the coil which opposes the reversal. This is the so-called reactance voltage referred to in commutation problems. The fact that two or more coils may be undergoing commutation at the same time involves consideration of mutual as well as self-induction. The relation of the mutual to the self-induction, the probable value of each, etc., lead to such mathematical complication in the analysis of the problem, that empirical methods have become the usual practice in dealing with commutation. The usual analytical methods do not permit a ready or easy physical conception of what actually takes place. One must think in formulas rather than in the phenomena of the commutation itself.

According to the usual theory, during the commutation of the coil the local magnetic flux due to the coil is assumed to be reversed. However, in the zone in which the commutation occurs, certain of the magnetic fluxes may remain practically constant in value and direction during the entire period of commutation. This is but one instance, of which there are several, to show where there is apparent contradiction of fact in the usual mathematical assumptions made in treating this problem.

The above fact of part of the flux in the zone of commutation remaining practically constant in value and direction, led the author to a method of dealing with the problem of commutation which is based upon consideration of the armature flux as a

NOTE:—This paper is to be presented at the 264th meeting of the A. I. E. E., New York, October 13, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

Digitized by Google

whole, as set up by the armature ampere turns. The results obtained by the method were very satisfactory, and it was apparent that a much better conception could be obtained of some of the phenomena of commutation than was possible with former methods.

In the following pages the method is indicated in general, and its application to interpole machines is then worked out in greater detail. In non-interpole machines the problem is greatly complicated by the presence of local currents under the brushes which modify the distribution of certain of the armature magnetic fluxes, as will be shown.

This theory of commutation, with the method of calculation, is based upon the broad principle of the *armature conductors cutting across the magnetic field set up by the armature winding and thereby generating an e.m.f. in the short circuited coils which is proportional to the product of the revolutions, the flux which is cut and the number of turns in series.* The usual "reactance" voltage due to reversal of the local flux of an individual coil is not considered, although its equivalent appears under another form.

The method in general is therefore the same as that used for determination of the main armature e.m.f., except that the magnetic fluxes cut by the armature conductors are those due to the armature magnetomotive force instead of those due to the field.

When the armature winding is carrying current its magnetomotive force tends to set up certain magnetic fields or fluxes which have a definite relation to the position of the brushes. Considered broadly, the current after entering the commutator or armature winding, at any brush arm, divides into two paths of opposite direction. As the winding on each of these paths is arranged in exactly the same way, and as the currents flow in opposite directions, the armature windings in these two paths have magnetomotive forces which are in opposite directions. The resultant armature magnetomotive force rises to a maximum at points corresponding to the brush positions. Midway between these points the magnetomotive force is zero. Magnetic fluxes are set up by these magnetomotive forces, which are a function of the force producing them, and the proportions, dimensions and arrangement of the magnetic paths; and these magnetic fluxes will be practically fixed in position corresponding to the brush setting.

Digitized by Google

The armature conductors cutting across these fluxes set up by the armature magnetomotive forces, will have e.m.fs. generated in them. In those conductors which have their terminals short circuited by the brushes, these e.m.fs. may be called the short circuit e.m.fs.

There are three principal armature fluxes which are cut by the short circuited armature coils. In the order of their usual importance these are,

1. That which crosses from slot to slot. It may be called the slot flux.

2. The interpolar flux which passes from the armature surface to the neighboring poles or yoke surface. It may be called the *interpolar* flux, as distinguished from *interpole* flux, which term will be used later.

3. That flux set up in the armature end-winding in the zone of the short circuited coil, due to the magnetomotive force of the end windings as a whole. It may be called the end flux.

The short circuited armature coils cutting across these three fluxes generate the short circuit e.m.fs. The whole problem of commutation may be considered as depending upon the predetermination of these three fluxes.

Consider, first, an armature conductor approaching the point of current reversal or commutation. Under this condition the current carried by the coil *always flows in the same direction as the e.m.f. generated by the conductor cutting across the magnetic field or flux set up by the armature winding is induced.* When the terminals of an armature coil pass under the brush and are short circuited, it is obvious that the e.m.f. set up in the coil by the armature flux is unchanged in direction for the coil is still cutting a field of the same polarity. This e.m.f. tends to maintain the current in the short circuited armature coil in the same direction as before but the value the current attains will be dependent upon the short circuit e.m.f. and largely upon the resistance in the circuit, which will usually consist of the resistance of the coil itself and of the brush contact. As the coil passes out of short circuit, that is, as it leaves the brush, the current must flow in the opposite direction, but the e.m.f. set up by the armature flux is still in the same direction as before. Therefore, after commutation, the armature current in the coil is flowing in opposition to the e.m.f. set up in the coil by the armature flux.

The following is a method for calculating approximately the three fluxes before described and the e.m.fs., generated by the

Digitized by Google

armature conductors cutting them. The interpolar fluxes will be considered first, the end fluxes second, and the slot fluxes last, as these latter are greatly complicated by the problem of local currents produced largely by the interpolar and end fluxes.

Interpolar Armature Flux

By this is meant the flux in the interpolar space between the armature core and the field poles and yoke, due to the magnetomotive force of the armature winding, as shown in Fig. 1. This magnetomotive force has its highest value at those parts of the armature winding corresponding to the brush contacts on the commutator and is zero midway between such points. If the brushes are set with zero lead then the maximum magnetomotive force of the armature lies midway between adjacent field poles and will taper off in value from this midpoint toward the

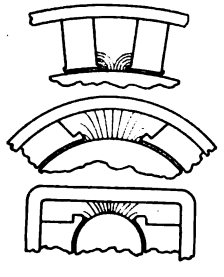


Fig. 1

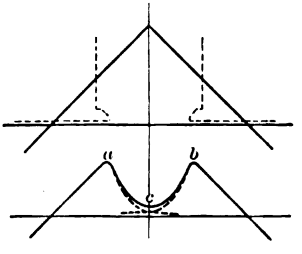


Fig. 2

adjacent edges of the poles. The flux density between the armature surface and the sides of the poles should therefore tend to taper off as the armature magnetomotive force is reduced but, in most types of field construction, it tends to increase in value due to the relatively shorter magnetic path as the edges of the poles are approached. Usually this increase very considerably overbalances the decrease due to the lower magnetomotive forces and in consequence the interpolar flux density due to the armature generally has a minimum value midway between the poles and rises toward the edges of the poles. This is illustrated by Fig. 2.

The density of this flux in the interpolar space is dependent upon many conditions such as the ampere turns of the armature winding per pole, distance between poles, conformation of the poles, yoke, etc. In Fig. 2 the ordinates of the dotted lines represent the flux densities at the armature interpolar surface

Digitized by Google

due to each of the two adjacent poles. The resultant of these two is the full line *a c b* which represents the distribution of the armature interpolar flux. This interpolar flux might be considered as a true magnetic field fixed in space with respect to the position of the brushes. This field being fixed and the armature conductors rotating it is obvious that any conductor moving across this magnetic field must have e.m.f. generated in it, the value of which depends upon the flux which is cut at any instant. Therefore, the e.m.f. due to this interpolar field can be determined directly, if the intensity of the field itself can be calculated.

During the period of commutation the armature coil is short circuited and has the current reversed in it under certain portions of this field. The problem is to determine the strength of the field corresponding to this point of commutation and then by direct calculation the corresponding e.m.f. can be determined. In the following analysis two cases will be considered, namely, pitch windings, and "chorded" or "fractional pitch" windings.

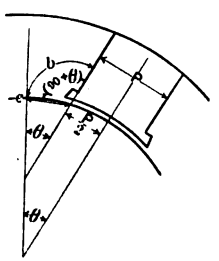


FIG. 3

Pitch Windings. When commutating or reversing a coil with a pitch winding it is evident that if there were no lead at the brushes such a coil would commutate, on the average, at the midpoint between two poles. The e.m.f. generated in the coil by cutting the interpolar field would therefore be proportional to the strength of the interpolar flux at the midpoint. This flux can be determined approximately in a fairly simple manner in the ordinary types of machines in which the poles are relatively long compared with the distance between adjacent pole tips and where the distance from the armature surface to the yoke is relatively great. The following is a method which appears to give reasonably close results:

Let W_t = total number of wires on the armature.

I_c = the current per conductor.

p = number of poles.

Then, the armature ampere turns per pole $= \frac{I_c \times W_t}{2\,p}$, neglecting any change in ampere turns due to the short circuiting action of the brushes.

In Fig. 3 let b represent the length of the mean flux path corresponding to the mid-interpolar position. This is assumed

Digitized by Google

to be a part of a circle which is practically at right angles to the armature surface and the side of the field pole, as indicated in Fig. 3.

Let P = width of body of pole.

Let B_i = the flux density at the midpoint between the poles.

Then $B_i = \frac{2 \times 3.19 \ I_c \times W_t}{2 \ p \ b}$.

But $b = 2 \pi a \frac{(90+\theta)}{360}$, approximately, as angle $(90+\theta)$ is only approximate.

Or $b = 2 \pi a \left(0.25 + \frac{\theta}{360}\right) = 2 \pi a \left(0.25 + \frac{1}{2 \ p}\right)$.

Also, $a = \left(\frac{\pi D}{2 \ p} - \frac{P}{2}\right)$ approximately.

Therefore

$$b = 2 \pi \left(0.25 + \frac{1}{2 \ p}\right) \left(\frac{\pi D - P p}{2 \ p}\right) = \frac{\pi \ (0.25p + 0.5) \ (\pi D - P p}{p^2}$$

Therefore

$$B_i = \frac{2 \times 3.19 \ I_c \ W_t \times p^2}{\pi \ (0.25p + 0.5) \ (\pi D - P p) \times 2 \ p}$$

$$\text{Or, } B_i = \frac{I_c \ W_t \ p}{(0.25p + 0.5) \ (\pi D - P p)} \text{ approx.}$$

The above gives the approximate flux density at the midpoint between poles. The flux densities at points at each side of the midpoint can be determined in a similar manner, taking into account the lower armature magnetomotive force as the midpoint is departed from. As the edge of the pole is approached the effect of pole horns may complicate the flux distribution so that the above method of calculating interpolar flux density will not apply for points close to the pole.

E.m.f. Due to Interpolar Flux.

Let E_c = The e.m.f. due to cutting the armature flux.

D = diameter of armature.

L = length of core including ventilating spaces.

T = turns per individual armature coil.

R_s = revolutions per second.

Digitized by Google

Then, the e.m.f. induced in a coil cutting the field at c (Fig. 2) can be represented by the formula,

$$E_c = \frac{B_i \times \pi D L \times 2 T_c \times R_s}{10^8}$$

Or,

$$E_c = \frac{I_c W_t p}{(0.25p+0.5)(\pi D - Pp)} \times \frac{2 \pi D L T_c R_s}{10^8}$$

Or

$$E_c = \frac{I_c W_t T_c R_s}{10^8} \times \left(\frac{2p \times \pi D L}{(0.25p+0.5)(\pi D - Pp)} \right)$$

Incidentally, with this method of dealing with the problem the effect of the addition of an interpole can at once be seen. The magnetomotive force of the interpole is superimposed on that of the armature and the resultant flux is then considered. The armature conductors cut this flux and thereby generate e.m.f. If the interpole magnetomotive force is stronger than that of the armature, then the flux established will be in the opposite direction in that part of the armature face which lies under the interpole. Therefore, the flux or field over the commutated coil in the non-commutating pole machine is replaced by flux in the opposite direction. The presence of the interpole does not increase the reactance of the armature coil as sometimes considered, but, on the contrary, the harmful flux is replaced by one which is of direct assistance in commutation.

Effect of Brush Width. In cutting across the interpolar flux it is obvious that the e.m.f. set up in the short circuited coil is not a function of the length of time the coil is short circuited, for this interpolar flux is set up by the armature winding as a whole and not by individual coils. If two or more armature coils in series are short circuited by the brush, then their e.m.fs. will be in series while the total resistance in the path will be very little higher than in the case of a single coil short circuited, for the principal part of the resistance lies in the brush contact. It is evident therefore that considerably higher short circuit currents can be set up by the interpolar field when more commutator bars, and more turns, are short circuited. It can therefore be assumed that, as far as the interpolar field is concerned, the more

Digitized by Google

commutator bars the brush covers the greater will be the short circuit current and the greater will be the difficulty in commutation, assuming there is no external field assisting commutation.

Chord Winding. With a pitch winding, with no lead at the brushes, the commutation of a coil will occur in the lowest part of the armature interpolar flux, as *a a* in Fig. 4. With a chorded winding, as indicated at *b b*, the commutation will occur under somewhat higher flux than with a pitch winding. Therefore in considering the interpolar flux a full pitch winding commutates under better conditions than a chorded winding.

End Fluxes

The armature winding as a whole sets up certain fluxes in the end windings. These fluxes are fixed in position with respect to the brushes, and the armature coils, in cutting across, them, generate e.m.fs. The only part of these end fluxes concerned in

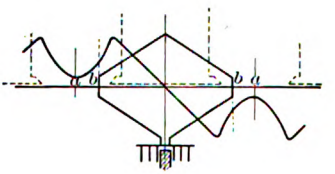


Fig. 4

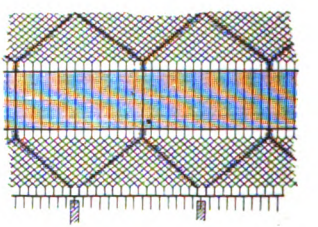


Fig. 5

the present problem is that which the commutating coils cut during the operation of commutation.

Fig. 5 illustrates an armature winding in which the heavy lines represent two coils in contact with the brushes and therefore at the position of commutation. It is only the end flux density along the shaded portion or zone of this diagram which need be considered. If the various densities for this zone can be determined, then the e.m.f. in the commutated coil can be calculated. Only the usual cylindrical type of end windings will be considered, as practically all direct current machines at the present time use this type. Such windings are usually arranged in two layers, the coils of which extend straight out from the armature core for a short distance, usually $\frac{1}{2}$ in. to $1\frac{1}{2}$ in., depending upon size and voltage of the machine, and then extend at an angle to the core of 30 deg. to 45 deg. The conductors of the upper and lower layers therefore usually lie almost at right angles to each other

Digitized by Google

Pitch Winding. Let Fig. 6 represent a single coil of the end winding located in the commutating zone. Both theory and test show that the maximum flux density in this zone is at *a* and tapers off slightly to *b*, then tapers off more rapidly from *b* until it reaches practically zero value at *c*. It may be assumed with but little error that the decrease from *b* to *c* is at a practically uniform rate. The flux density along the commutating zone of the end winding may therefore be represented by Fig. 7, in which the ordinates represent flux density. On the above assumption the total flux in the commutating zone of the end winding can be determined with sufficient accuracy if the density at *b*, for instance, can be determined and the distances *a b* and *c d* in Figs. 6 and 7 are known. These latter can be determined directly from the winding dimensions.

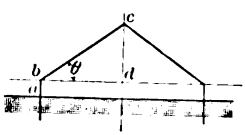


FIG. 6

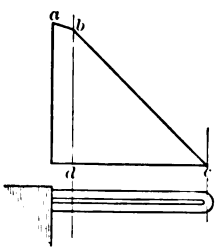


FIG. 7

The following is an approximate formula for the flux density at *b*, including allowance for proximity of iron end plate, core, etc.

$$B_e = \frac{2.65\, I_c\, W_t \times \log 2N}{\pi\, D \sin\theta}$$

N = number of slots per pole.
I_c = current per conductor.
W_t = total armature wires.
D = diameter of armature.
Let $a\,b = h$, and $c\,d = m$.

Then the flux cut by one conductor at one end is

$$\pi\, D \left(h + \frac{m}{2}\right) \times \frac{2.65\, I_c\, W_t \times \log 2N}{\pi\, D \sin\theta}$$

Therefore the e.m.f. per single turn of the armature winding,

Digitized by Google

due to the end flux, considering the end fluxes for both ends of the core, becomes

$$E_c = 2\left(h+\frac{m}{2}\right)\times\frac{2.65\, I_c\, W_t \times \log 2\, N}{\pi\, D \sin\theta}\times\frac{\pi\, D\, R_s \times 2\, T_c}{10^8}$$

Or,

$$E_c = \frac{I_c\, W_t\, T_c\, R_s}{10^8}\times\frac{5.3\,(2\,h+m)}{\sin\theta}\times\log 2\, N$$

This formula is on the basis of non-magnetic paths around the end windings, that is, with no bands of magnetic material and no magnetic supports under the coils. The effect of bands over the end winding is approximately equivalent to cutting the flux path to half length for those parts of the end winding covered by the bands. Therefore, with bands, the diagram representing flux density in the commutating zone of the end winding would be as indicated in Fig. 8. In this case the total flux corresponds to the total area of the curve including the dotted portion. Of course the actual flux distribution would not be exactly as shown in this diagram for there would be some fringing in the neighborhood of the bands. The diagram simply serves to illustrate the general effect of magnetic bands and an approximate method of taking it into account.

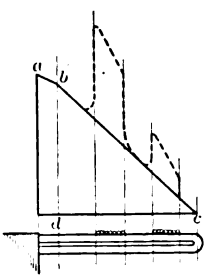


FIG. 8

The effect of a magnetic coil support will be very similar to that of a steel band in reducing the length of path and therefore increasing the flux in the neighborhood of the coil support. However, in case of magnetic bands over the winding and coil supports under it the limit lies in saturation of the bands themselves. This usually represents a comparatively small total flux. The coil support, however, would probably not saturate in any case.

The above formula for end flux can therefore be corrected for magnetic bands and coil supports by multiplying by a suitable constant to cover the increased flux.

It is obvious that the determination of the end flux is, to a certain extent, a question of judgment and experience. No

Digitized by Google

fixed method or formula can be specified for all types of machines, for this flux would be influenced very greatly by the bands, if of magnetic material, and by the material, size and location of the coil supports and their relation to the bands. Also, eddy currents may be set up in the coil supports which will influence the distribution of the end flux in the zone of the commutated coil. However, in each individual case an approximation can be made which will, in general, be much closer than would be obtained from any empirical rule or by neglecting the effect of the end flux altogether.

Chord Winding. The effect of chording the armature winding is to slightly diminish the flux density in the commutating zone which results in a slight reduction in the e.m.f. of the commutating coil. But a relatively much greater gain is obtained by the consequent shortening of the distance *c d* in Fig. 8 and the corresponding reduction of the total end flux. Due to the chording itself the flux density at *b* is reduced practically in the ratio of $\frac{\log 2\,N_1}{\log 2\,N}$, where N_1 = number of slots spanned by the coil. For example, if the full pitch is 20 slots and the coil spans 18 slots, then the density at *b* will be reduced in the ratio of $\frac{\log 36}{\log 40} = 0.971$ due to the chording itself; and the flux along *c d*, Fig. 7, will be further reduced in the ratio of $\frac{18}{20}$ due to the shorter end extension. The average flux along *c d* therefore will be reduced to $0.9 \times 0.971 = 0.874$, or about 87 per cent of that of a pitch winding.

Effect of Brush Width. As in the case of the interpolar flux the width of the brush, or the number of armature coils short circuited by the brush, has practically no influence on the e.m.f. generated per turn. However, the total effective armature ampere turns will be reduced slightly, if the average current in the short circuited turns is less than the normal current. This will have a very slight effect on the e.m.f.

Slot Flux

By this is meant the magnetic flux across and over the armature slots which does not extend to the yoke or field poles.

Two general cases will be considered; first, that in which no local currents are present, which is the case in well designed interpole machines; and second, that in which there are local

Digitized by Google

currents set up in the short circuited coils, which is almost invariably the case in machines without interpoles or some other form of compensation. Also, pitch and chorded windings will be considered.

Slot Flux with No Local Currents

Pitch Winding. Let Fig. 9 represent an upper and a lower coil in the same slot, with equal turns and currents. Then if there is no saturation in the adjacent teeth the flux density across the slot will be zero at the bottom of the lower coil and will rise to a maximum value at the top of the upper coil. There will also be a flux across the slot above the upper coil and also from the top of the tooth as indicated in Fig. 9. The total slot flux entering at the bottom of the teeth is therefore equal to the total flux which crosses the two adjacent slots, plus the flux crossing at the top of the slots. The interpolar flux which ex-

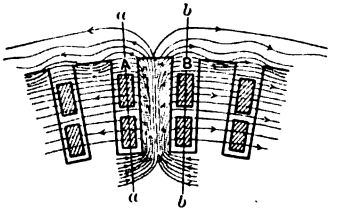


Fig. 9

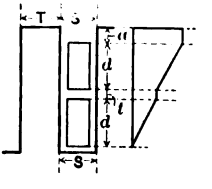


Fig. 10

tends from the armature surface to the poles or yoke is not included in this.

As this slot flux is practically fixed in position the armature conductor in slot A, in passing from a to b must cut this flux. It is obvious that the flux which crosses above the uppermost conductor in the slot is cut equally by all the conductors in the slot, as the coil passes from position a to position b; but the flux crossing the slot below the uppermost conductor does not affect all the conductors equally, and therefore, for simplicity of calculation, an equivalent flux of lower value can be used which may be considered as cutting all the conductors equally.

Let d Fig. 10, represent the depth of the conductors of one complete coil.

t represent the distance between the upper and lower coils.

a represent the distance from the upper conductor to the core surface.

Digitized by Google

s represent the width of the slot, assuming parallel sides.
n represent the ratio of width of armature tooth to the width of the armature slot, *at the surface of the core.*
T_c represent turns per single coil, or per commutator bar.
C_s represent the number of individual coils, or commutator bars, per complete coil.
L represent the width of armature core, including ventilating spaces.
I_c represent the current per armature conductor.

Then, ampere turns per upper or lower coil $= I_c T_c C_s$.

$$\text{Total flux across coil space} = \frac{3.19 I_c T_c \times C_s L (2d+t)}{s}$$

$$\text{Flux across slot above coil} = \frac{3.19 I_c T_c C_s L \times 2 \times a}{s}$$

Flux from tooth top across the slot is approximately,

$$3.19 I_c T_c C_s L \times 2 \times 0.54 \sqrt{n}$$

$$\text{Total flux above upper coil} = 3.19 I_c T_c C_s L \frac{(2a+1.08 s \sqrt{n})}{s}$$

The sum of the two fluxes represents the total flux across one slot which enters at the bottom of one tooth. As a similar flux passes across the slot at the other side of the tooth the total flux entering the tooth will be double the above and becomes

$$\text{Total slot flux} = 2 \times 3.19 I_c T_c C_s L \frac{(2d+t+2a+1.08 s \sqrt{n})}{s}$$

This total flux cannot be used directly in the calculations as it does not affect all the conductors equally. It is therefore necessary to determine equivalent fluxes for the upper and lower coils which can be used instead of the above value.

For the lower coil the following value has been calculated:

$$\text{The equivalent flux} = \frac{2 \times 3.19 I_c T_c C_s L}{s} (1.833 d+t)$$

And for the upper coil,

$$\text{Equivalent flux} = \frac{2 \times 3.19 \times I_c T_c C_s L}{s} \times 0.833 d$$

To these equivalent fluxes should be added the total flux above the upper coil. This gives the total effective flux for the upper and lower coils. Then, for the lower coil,

Digitized by Google

Total effective flux

$$=2\times 3.19\, I_c\, T\, C_s\, L \left(\frac{1.833\, d+t+2\, a+1.08\, s\, \sqrt{n}}{s}\right)$$

And for the upper coil,
Total effective flux

$$=2\times 3.19\, I_c\, T_c\, Cs\, L \times \frac{(0.833+2\, a+1.08\, s\, \sqrt{n})}{s}$$

The average value of the effective flux for the upper and lower coils then becomes,

$$3.19\, I_c\, T_c\, C_s\, L\, \frac{(2.67\, d+t+4\, a+2.16\, s\, \sqrt{n})}{s}$$

(This average effective value is approximately 80 per cent of the total slot flux.)

On the basis of a pitch winding and the assumption that only one armature coil is short circuited, that is, with the brush covering the width of only one commutator bar, then the above slot flux is cut by all the coils in the slot in passing through one slot pitch. From this the e.m.f. in the commutating coil due to the slot flux can be calculated directly and may be expressed as follows:

$$E_c=\frac{2\, T_c\, R_s}{10^8}\times \text{number of slots}$$

$$\times 3.19\, I_c\, T_c\, C_s\, L\, \frac{(2.67\, d+t+4a+2.16\, s\, \sqrt{n})}{s}$$

But $C_s\times$ number of slots = No. of commutator bars

$$=\frac{\text{total number of conductors}}{2\, T_c}=\frac{W_t}{2\, T_c}$$

Therefore the above expression for e.m.f. may be changed to the form,

$$E_c=\frac{3.19\, I_c\, W_t\, T_c\, R_s\, L}{10^8}\quad\frac{(2.67\, d+4\, a+t+2.16\, s\, \sqrt{n})}{s}$$

If it is desired to compare this expression with a certain well known formula which has been much used heretofore, then let

Digitized by Google

the quantity in the parenthesis in the above expression be represented by c_x. The formula can then be changed to,

$$E = (2\times 3.19\times c_x)\times \frac{I_c\, T_c^2\times \text{number commutator bars}\times R_s\times L}{10^8}$$

It contains the same terms (except in the value of the constant) for the expression of the e.m.f. which has been used heretofore in determining the reactance of the commutated coil.

Effect of Brush Width or Number of Commutator Bars Covered by Brush. The above formulas are on the basis of the brush covering only the width of one commutator bar. In this case all the conductors of one slot cut across the entire slot flux in passing through one tooth pitch. However, if the brush covers more than one commutator bar, then the full slot flux is not cut in passing through one tooth pitch, and a movement greater than one tooth pitch is required for full cutting. For example, if there is one commutator bar per armature slot and the brush covers a width equal to two commutator bars, then the total cutting of the slot flux will take place in two tooth pitches. Again, if there are three commutator bars per armature slot and the brush covers the width of one commutator bar, then the total cutting of the total slot flux would occur in one tooth pitch, while if the brush covered two bars, the total cutting would occur in $1\frac{1}{3}$ tooth pitches; and if it covered three bars $1\frac{2}{3}$ tooth pitches are required. In other words, the total cutting will occur in a period corresponding to the number of commutator bars per slot plus one less than the number of commutator bars covered by the brush.

On this basis the correction factor for the slot e.m.f. should be expressed by the term $\frac{C_s}{C_s+B_i-1}$, where C_s = number of commutator bars per slot, and B_i = number of commutator bars spanned by the brush. However, with several coils per slot, and with the brush spanning several bars, the rate of cutting of the tooth flux for the entire period is not quite the same as the rate for one tooth pitch. Taking this into account the correction factor should not be equal to $\frac{C_s}{C_s+B_i-1}$, but is slightly greater. Up to four commutator bars per slot, and three bars

Digitized by Google

spanned by the brush the correction factor can be expressed by the term $1+\frac{1}{B_i C_s} - \frac{1}{C_s}$.

Taking the lengthened period of reversal into account, it would appear that a wide brush covering a large number of commutator bars should be beneficial in reducing the e.m.f. generated by the slot flux. This is true where the local currents are very small, or are absent, as is the case in a properly designed interpole machine. In a non-interpole machine where the local currents in the short circuited coils may be relatively high, this condition does not hold, as will be explained later.

The above formula for e.m.f. due to the slot flux should therefore be modified by multiplying by a factor which takes into account the period of reversal as affected by brush width.

Chord Winding. The armature winding may be chorded one or more slots and, in some instances, where there are several coils side by side there has been chording of part of the conductors in the slot. In Fig. 11 is illustrated the conditions with one-slot chording. The total slot flux now occupies two teeth instead of one. Therefore the e.m.f. set up by cutting across this slot flux will be approximately one-half that which is obtained with a full pitch winding, on the basis of the brush covering the width of one bar only, for the e.m.f. generated by cutting this flux will be reduced in proportion as the period of cutting is increased. There is one slight difference from the flux distribution with a pitch winding, namely, that at the top of the teeth. With a chorded winding this flux will be slightly greater than with a pitch winding, but the total effect of this difference should be relatively so small that ordinarily the value need not be changed. Therefore equivalent fluxes used with chord windings can be taken the same as for pitch windings. In consequence, the e.m.f. *due to the slot flux*, with one-tooth chording, may be taken as one-half that for a pitch winding, with the brush covering one commutator bar in both cases.

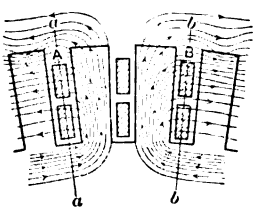


FIG. 11

For two-slot chording the slot flux may be considered as occupying the space of two teeth only, while there will be a magnetically idle tooth at the center. The e.m.f. per coil actually generated by cutting the slot flux will be, for part of the period,

Digitized by Google

the same as for one-slot chording, but there will be an intermediate period where the slot e.m.f. is practically zero, which does not occur with a one-slot chording or with a pitch winding. The average results, however, should be practically the same as if the total slot flux were actually distributed over three teeth instead of two.

Effect of Brush Width with Chord Winding. In the chord winding, when the brush covers two or more commutator bars, the period of cutting the slot flux will be lengthened just as with a pitch winding on the assumption of no local currents. For example, if there are three commutator bars per armature slot and the winding is chorded one slot, then with the brush covering one commutator bar, complete cutting of the slot flux will occur in the space of six commutator bars. If the brush covers three commutator bars instead of one, then complete cutting will occur in the space of eight commutator bars, while in a corresponding full pitch winding it would occur in the space of five bars. Therefore, the wide brush represents an improvement with the chorded winding, but not to the same extent, relatively, as with the pitch winding. This is on the assumption of absence of local currents in the short circuited coils.

Bands on Armature Core. By the preceding method of analysis the effect of bands of magnetic material on the armature core can be readily taken into account. This effect represents simply an addition to the total flux which can pass up the tooth and across the top of the slots. From the ampere turns per slot, the clearance between the bands and the iron core, the total section of the band, etc., the flux due to the band can be calculated. This flux can either be combined directly with the slot flux already described and the resultant e.m.f. can then be calculated; or, the e.m.f. can be calculated independently for the band flux alone. Magnetic bands on the armature introduce a complication into the general e.m.f. formula due to the fact that in many cases the flux into the bands is such as to highly saturate the band material at relatively low armature currents. This flux therefore is usually not proportional to the armature ampere turns. If the e.m.f. due to the band flux is to be calculated separately, the following formula can be used:

ϕ_b represents the total magnetic flux in the band from the armature core considering both directions from the tooth, then

$$E_c = \frac{2\,\phi_b\,N\,p\,T_c\,R_s}{10^8}$$

Digitized by Google

This formula holds true for the band flux which passes through the one tooth in the pitch winding. Proper allowance must be made for the effect of chord windings and brush width, which can be done by the methods already described.

Slot Flux with Local Currents

Pitch Winding. In the preceding analysis local currents have not been included, as the method would be greatly complicated by taking such currents into account. In the general method given below the effect of local currents in the short circuited coils can be most easily shown.

As already explained, an armature coil, as it approaches the short-circuit condition, has an e.m.f. generated in it by the interpolar and the end fluxes. After the coil is short circuited this e.m.f. is still generated by the coil and naturally a local or short circuit current tends to flow through the coil, brush contact

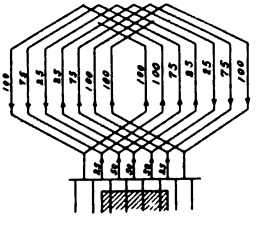


Fig. 12

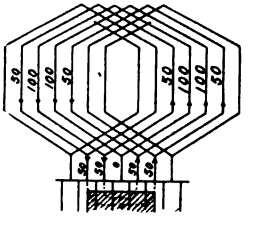


Fig. 13

and brush. In addition, the work, or supply, current is being furnished to the armature winding through the brushes. These two currents are superimposed in the short circuited winding in such a way as to have a very pronounced influence in the distribution of the slot fluxes. This effect can be best seen by first determining the distribution of the work current in the various parts of the short circuited winding on the assumption of *no local current* and second, determining the distribution of the local currents on the assumption of no *work current, but with the same armature magnetomotive force* as in the first assumption. The two distributions can then be combined and the resultant currents in the various parts of the short circuited coils can be obtained.

Let Fig. 12 represent the first assumption in which no local currents are present. In order to illustrate conditions to better advantage, four commutator bars are assumed to be covered by the brush. Uniform distribution of current over the brush contact can be assumed in this case, as there are no local currents.

Digitized by Google

Tracing out the current in each short circuited coil in Fig. 12, it will be seen that the current decreases at a uniform rate and then rises in the opposite direction at the same rate until the short circuit is removed. The period of commutation is the longest possible with this number of commutator bars short circuited, and the brush conditions are ideal, as the current density at the brush contact is uniform at all parts. The above are the conditions which the designer endeavors to obtain in the construction of good interpole machines, as will be shown later.

In Fig. 13 the same arrangement of winding and brushes is chosen as in Fig. 12 except that only the local currents are shown and the values of these are assumed as proportional to the e.m.fs. in the short circuited coils and the resistance in circuit. In this diagram the current is a minimum in the coils at the moment that short circuit occurs, and rises to a maximum value and then diminishes to zero value again at the end of the short circuit.

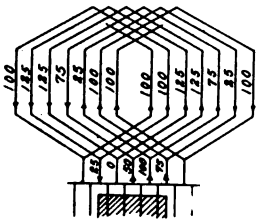


FIG. 14

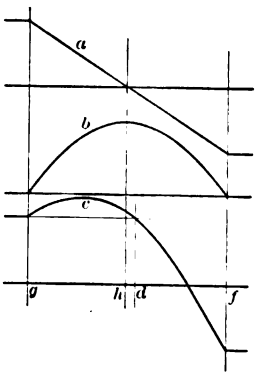


FIG. 15

In Fig. 14 the currents of Fig. 12 and 13 are superimposed. The resultant currents in the various parts of the short circuited winding are seen to rise after short circuit until a maximum value is reached and then decrease rapidly and reverse to normal value in the opposite direction. Therefore, the period from normal value of the current to normal in the opposite direction is very much shorter than when no local currents are present. It may therefore be considered that the period of reversal is much reduced by the presence of the local currents, so that the e.m.f. in the short circuited armature conductors generated by the slot flux is proportionately increased, compared with the value it would have in case the local currents were absent. These conditions can be shown possibly in a somewhat better manner by curves *a*, *b* and *c* in Fig. 15. The curve *a* shows the distribution of current in the short circuited coils without any local currents. Curve *b* shows the distribution of local currents.

Digitized by Google

while curve c shows the resultant of the two. The distance between d and f on curve c gives the period of reversal from normal current in one direction to normal current in the opposite direction. This period is much shorter than the full period represented by $g\,f$ which would be obtained without local currents. The period $d\,f$, however, may not differ much from the period of commutation with the brush covering the width of only one bar, when the local current is high compared with the work current. In such case the gain in the period of commutation which should be obtained by means of the wider brush may be practically offset by the effect of the local currents which also increase with the wider brush, so that over a considerable range the resultant of the two effects may be practically constant. This is one indication why, in non-interpole machines, the brush width may be varied over quite a range with relatively small noticeable difference in the commutation. This may be il-

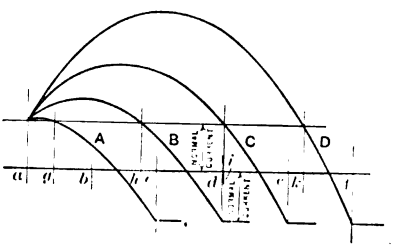


FIG. 16

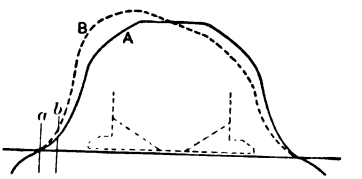


FIG. 17

lustrated by Fig. 16, in which is shown the current conditions with two to five bars spanned. In this figure $a\,b$, $b\,c$, $c\,d$, etc., each represent the width of one commutator bar. Therefore, curve A, extending over the width $a\,c$, represents two bars spanned. The period of reversal of the current from normal value in one direction to normal in the opposite direction is represented by $g\,c$ for curve A, $h\,d$ for curve B, $i\,e$ for C and $k\,f$ for D. A comparison of these values is interesting. Calling $a\,b$ the period of reversal with the brush covering one bar only, then $g\,c$ with two bars covered, is greater than $a\,b$. $h\,d$ is also greater than $a\,b$, but less than $g\,c$, while $i\,e$ is slightly less than $a\,b$, and $k\,f$ is considerably less. However, the variation between $g\,c$ and $k\,f$ is much less than between $a\,c$ and $a\,f$ which would be the corresponding periods with no local currents.

It should be borne in mind that the above curves are only relative, depending upon the comparative values of the local and work currents and assuming a constant brush resistance

Digitized by Google

which is not correct, but they serve to illustrate the general principle. This method of presentation is simply a skeleton of the problem of commutation when local currents are present in the short circuited coils and it would be beyond the scope of this paper to attempt a full solution.

Effects of Field Distortion. One of the "bugaboos" of the designer of commutating machines has been the question of field distortion. It has usually been considered that when the machine is loaded the magnetic field is more or less distorted or shifted from its normal no-load position and that commutation is affected by this distorted field.

To state the case plainly, the field distortion has practically nothing to do with the problem. The distorted field magnetism is simply a resultant of the no-load main field flux combined with that due to the armature winding. Therefore, the two components of the distorted full-load field are the no-load main field, which is fixed in space and is usually practically constant, and the armature field, which is also fixed in space but varies with the load. If the brushes are set in a certain position with respect to the no-load field, then, as this component of the resultant full load field is practically fixed in space and in value, it has no variable influence on the commutating conditions. The true variable element which does affect the commutation is the armature field, or flux, and it is in this very flux which is the basis of the preceding theory of commutation. Therefore, the distorted resultant field of a loaded machine does not present any new condition in the problem of commutation. One exception, however, can be made to the above, namely, where there is any considerable saturation in the armature teeth or in the main field pole corners. The effect of the armature magnetomotive force is to strengthen one corner or edge of the field pole and to weaken the other edge, but when saturation is pronounced the strengthening action is much less than the weakening action. The resultant of these actions is a decrease in the total value of the main field flux. If, now, this main field flux be brought back to its normal total value, or higher, a very considerable addition to the main field magnetomotive force will be necessary, which will be effective in increasing the field flux at the weaker pole corner to a much greater extent than at the highly saturated pole corner. In consequence, with load, the main field distribution, or field form, may be considered as being changed from its no-load form A, to the form B, as indicated in Fig. 17. It is, in reality, strengthened at a point b, for

Digitized by Google

example. In such case the main field will have a variable influence on the commutation, if the brush is set with a lead, as at *b*, and, to a slight extent, the effect of an interpole is thus obtained.

Effect of Brush Lead. Before taking up the problem of interpoles on direct current machines it might be well to consider the effect of brush lead, as this gives a result intermediate between true interpole and non-interpole commutating conditions.

The preceding formulas apply to non-commutating pole machines without brush lead. However, except in case of reversing machines, such as street railway motors, or hoist motors, etc., it is usual practice to give a forward lead to the brushes of direct current generators or a slight backward lead to direct current motors. The effect of giving a lead at the brushes of a non-interpole direct current machine may be considered as being equivalent to the effect of an interpole with the exception

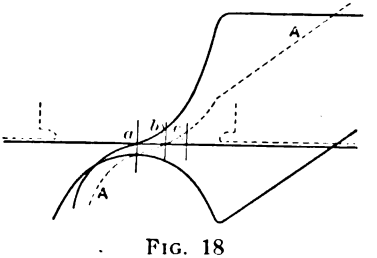


FIG. 18

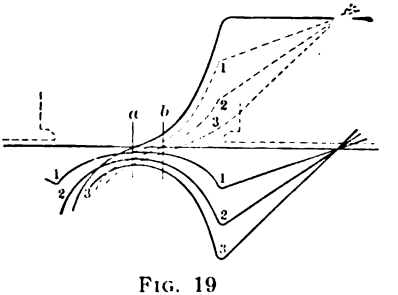


FIG. 19

that correct flux conditions and proper commutation, with any given brush setting, are obtained only for one given load.

As described before, with a non-interpole machine the armature winding sets up a flux in the interpolar space. With no-lead at the brushes this flux is usually a minimum midway between the poles and rises toward the polar edges. The flux from the adjacent main poles has a zero value midway between the poles and rises toward the polar edges, but has opposite polarities at the two sides of the midpoint. This is illustrated in Fig. 18. The resultant of the armature and field fluxes is indicated by the dotted line *A*. This resultant falls to zero at one side of the midpoint and then rises in the direction opposite to that of the flux due to the armature ampere turns. At the other side of the midpoint the two fluxes add, giving an increased resultant flux in the same direction as the interpolar flux due to the armature. From this figure it is evident that if the point of

Digitized by Google

commutation is shifted from *a* to the point of zero interpolar flux *b*, then commutation will occur without any interpolar flux to be taken into account, that is, the e.m.f. generated by the short circuited armature conductors may be due to the slot and end winding fluxes only. If the brushes are shifted still further in the same direction to *c*, then, not only will the interpolar armature flux be annulled but a flux in the opposite direction would be cut by the short circuited armature conductor, which will generate an e.m.f. in opposition to that due to the armature fluxes in the slots and end windings. Consequently, the commutation can be materially assisted by such lead at the brushes.

The difficulty in the use of this method of commutation lies in the fact that the commutating or reversing flux at *c* is the resultant of the main field flux and the armature interpolar flux at this point, and the latter flux varies with the load, while the former remains practically constant. Therefore the zero point of the resultant field shifts backwards or forwards with change in load and the density of the commutating field beyond the zero point will therefore change with the armature current. In consequence, if the brushes are shifted into a suitable resultant field *c* at a given current, then with a different load the intensity of this field at *c* will be changed, and unfortunately the change will be *in the opposite direction* from that desired. In other words, the density of this resultant field will decrease with increase in load, whereas just the opposite effect is desired for good commutation over a wide range in load.

In practice, however, an average condition is found which, in many cases, will give reasonably good commutation over a relatively wide range in load. The brushes may be shifted at no-load into an active field in such a way as to generate an e.m.f. in the armature coils of a comparatively high value. This e.m.f. will circulate considerable local current through the brush contacts and the amount of lead which can be given is dependent, to a certain extent, upon the amount of local current which can thus be handled without undue sparking.

As the load is increased the strength of the resultant field, corresponding to this brush position, will be decreased, and with some value of the current this field will be reversed in direction. At this point the e.m.f. due to this field is added to the e.m.f. due to the slot and end winding fluxes. Obviously the limiting condition of commutation will be reached at a much higher current than would be the case if no load at all had been given. This condition is represented in Fig. 19, in which curves 1, 1, 2, 2, 3, 3,

Digitized by Google

etc., represent the armature and resultant flux distributions with various loads. In this figure the brushes are given a lead so that commutation occurs at a point corresponding to *b*.

It is obvious that at heavy load a still greater lead at the brushes might give improved commutating conditions. However, if the load were suddenly removed without moving the brushes toward *a*, then the short circuited coils would be cutting the main field at such density that serious sparking or flashing might occur.

One serious objection to this method of commutation is that the distribution of the resultant field is practically such that equally good commutation cannot be obtained for all the coils in one slot when there are several coils or commutator bars per slot. All the coils of one slot must pass under a given position or value of the interpolar magnetic field at the same instant, while the commutator bars to which these coils are connected must pass under the brush consecutively. If the field intensity is just right for good commutation as the first coil per slot passes under the brush, then it may be entirely too great by the time the last coil is commutated. For good commutation with a number of coils in one slot, the resultant interpolar flux should have practically constant value over the whole range represented by the period of commutation of all the coils in one slot. This condition, however, is extremely difficult, or is frequently impracticable, to obtain with the ordinary non-interpole machine.

The above treatment of the problem of the effect of the brush lead has been based upon the armature interpolar magnetic field being located in the same position with lead as when there is no lead at the brushes. It has been assumed heretofore that the non-interpolar flux due to the armature winding has a minimum value midway between the main poles and rises uniformly toward two adjacent pole corners. This, however, is only true when the point of commutation, or brush setting, is midway between the poles. When the brushes are shifted toward either pole the point of maximum armature magnetic potential is shifted in the same way. This means that the distribution of the armature interpolar flux will be modified directly by the position of the brushes. Instead of rising uniformly toward the two pole corners, with a minimum value midway between, it will have a minimum at one side of the midpoint, this being at the opposite side from the point of brush contact, and will have

Digitized by Google

an increased value on the side toward which the brushes are shifted. This is illustrated in Fig. 20 in which *A* represents the armature interpolar flux distribution with the brush at *a*, while *B* represents it with the brush at *b*.

This increased armature interpolar flux due to the brush shifting means that the resultant interpolar flux due to both the armature and main field fluxes will cross the zero line at a point further removed from the midpoint than in the case of no lead at the brushes. Consequently, in order to obtain a given useful commutating field the brushes must be given a greater amount of lead and this in turn shifts the zero point still further. Thus, the act itself of shifting the brushes makes the commutating conditions more difficult.

The calculation of the commutating conditions with any given lead therefore resolves itself into a determination of the re-

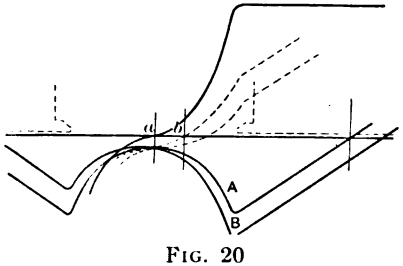


FIG. 20

sultant fluxes in which the coil is short circuited or commutated and the e.m.fs. generated by such fluxes. For the slot and end winding fluxes the calculation will be the same as for no-lead at the brushes. The resultant flux in the interpolar space is the only condition which will introduce any variation from the preceding formulæ and methods of calculation. This part of the problem resolves itself simply into the determination of the resultant interpolar flux at the point of commutation for any given load. The corresponding e.m.f. can then be calculated. This, combined with the e.m.fs. due to the slot and end windings, gives the total short-circuit e.m.f. The method is, in principle, exactly the same as given before, except that the determination of the interpolar flux will be modified.

Summation of Formulæ. In order to obtain the total voltage in the short circuited coil a summation should be made of the four separate voltages which have been derived for the interpolar,

Digitized by Google

end, slot and band fluxes. In reality it is the resultant fluxes which should be combined, but as the voltages to be derived from these fluxes represent somewhat different terms, a better procedure appears to be the summation of the voltages. Also, in practice it is the e.m.fs. generated by the different fluxes, rather than the fluxes themselves, which are desired.

The e.m.f. derived from the interpolar flux is

$$E_c = c_1 \times \frac{I_c\ W_t\ T_c\ R_s}{10^8} \quad \frac{2\ p\ \pi\ D\ L}{(0.25\ p+0.5)\ (\pi\ D - P\ p)}$$

where c_1 is a correcting factor for chord winding, etc.

The formula for the end flux voltage is,

$$E_c = c_2 \times \frac{I_c\ W_t\ T_c\ R_s}{10^8} \times \frac{5.3\ (2\ h+m)}{\sin\ \theta} \times \log\ 2\ N$$

where c_2 represents the correcting factor for chord windings, etc.

The formula for the slot flux voltage is,

$$E_c = c_3 \times \frac{3.19\ I_c\ W_t\ T_c\ R_s\ L}{10^8} \quad \frac{(2.666\ d+4\ a+t+2.16\ s\ \sqrt{n})}{s}$$

where c_3 is the correcting factor for the brush width, chord winding, etc., and,

For the bands,

$$E_c = c_4\ \frac{2\ \phi_b\ N\ p\ T_c\ R_s}{10^8}$$

where c_4 is the correcting factor for chord winding, brush width, etc.

Therefore,

$$E_c\ \text{total} = \frac{I_c\ W_t\ T_c\ R_s}{10^8} \left[c_1 \left(\frac{2\ p\ \pi\ D\ L}{(0.25\ p+0.5)\ (\pi\ D - P\ p)} \right) + \right.$$

$$c_2\ \frac{5.3\ (2\ h+m)}{\sin\ \theta}\ \log\ 2\ N +$$

$$\left. c_3 \left(3.19\ L\ \frac{(2.666\ d+4\ a+t+2.16\ s\ \sqrt{n})}{s} \right) \right]$$

$$+ c_4 \times \frac{2\ \phi\ N\ p\ T_c\ R_s}{10^8}$$

Digitized by Google

It is evident from this last equation that when there are no bands over the core the total e.m.f. in the short circuited coil is directly proportional to the current per armature coil or conductor. If the bands saturate, as would usually be the case with any considerable load, then the e.m.f. is no longer directly proportional to the current. Attention is called to this point as it has some bearing in the design of interpole machines.

Condensed Approximate Formula. The above formula can be simplified very considerably by certain approximations which introduce but little error within the range of ordinary design.

First, the expression, $\frac{p}{(0.25\ p+0.5)\ (\pi\ D-P\ p)}$ does not seem to be capable of any general simplification. In fact, as shown from its derivation, it is not a general term, but applies only to certain constructions and may appear in a quite different form for other constructions. Therefore this expression must be used with judgment in any case. Moreover, this term appears only in non-interpole machines or in interpole machines only when the interpoles are narrower than the armature core or the number of interpoles is less than that of the main poles. Therefore this term may be neglected in many cases where interpoles are used.

Second, the expression $5.3\ \frac{(2\ h+m)}{(\sin\ \theta)}\ \log\ 2\ N$ can be changed as follows:

$5.3\ \frac{(2\ h+m)}{(\sin\ \theta)}=\frac{4\ \pi\ D}{p}$, with reasonable accuracy within the ordinary limit of design,

And $\log\ 2\ N=0.9+0.035\ N$, with an error of about 4 per cent within the range of 6 to 24 slots.

Therefore $5.3\ \frac{(2\ h+m)}{(\sin\ \theta)}\ \log\ 2\ N=\frac{4\ \pi\ D}{p}\ (0.9+0.035\ \ N)$, approximately.

This is simpler to handle, in practice, than the original term.

Third, the expression, $\frac{2.666\ d+4\ a+t+2.16\ s\ \sqrt{n}}{s}$ can be simplified very materially.

Let the total depth of slot be represented by d_s, which is equal to $2\ d+a+1.5\ t$, approximately.

Then, the term, $2.666\ d+4\ a+t$ can be changed to $\frac{4d_s}{3}+\frac{8\ a-3\ t}{3}$

Digitized by Google

Assuming $a=0.25$ and $t=0.15$, then

$$\frac{8a-3t}{3}=0.52 \text{ approximately.}$$

$$\text{Therefore, } \frac{2.66d+4a+t}{s}=\frac{4d_s}{3s}+\frac{0.52}{s}$$

This is a very close approximation within the ordinary working range of slot dimensions. Therefore, the above expression becomes, $\frac{4d_s}{3s}+\frac{0.52}{s}+2.16\sqrt{n}$, which is much simpler to use in practice.

Fourth, in the simplified equation π appears in the first and second terms, and 3.19 appears in the third term. These are so nearly equal that π may be used as a common factor for the three terms.

The combined formulæ for the total voltage per armature coil thus becomes, in approximate form,

$$E_c=\frac{I\ W_t\ T_c\ R_s\ \pi}{10^8}\left[c_1\frac{2pDL}{(0.25p+0.5)(\pi D-Pp)}\right.$$

$$+c_2\frac{4D}{p}(0.9+0.035N)+$$

$$\left.c_3L\frac{(1.33\ d_s+0.52+2.16\ s\sqrt{n})}{s}\right]+c_4\frac{2\phi_b\ Np\ T_c\ R_s}{10^8}$$

This appears to be about as simple a form as the equation can be put into when all the factors are to be included. It will be shortened for machines without magnetic bands on the core, and in many interpole machines the term derived from the interpolar flux may be omitted. For a given line of machines which are all of similar design, etc., it is probable that the terms can be further combined and simplified.

Interpolar Machines

In the interpole machine a small pole is placed between two adjacent main poles for the purpose of setting up a local magnetic flux under which the armature coil is commutated. This local

Digitized by Google

flux, in order to assist commutation, must be opposite in direction to the interpolar flux set up by the armature winding itself. To set up this flux in the opposite direction the magnetomotive force of the interpole winding obviously must be greater than that of the armature winding in the commutating zone.

An armature coil, cutting across this interpole flux, generates an e.m.f. proportional to the flux, the speed and the number of conductors in series. This e.m.f. is in opposition to the e.m.f. in the short circuited coils, generated by the slot and end winding fluxes. For ideal commutation these e.m.fs. are not only in opposition, but they should also be of practically equal value. For perfect commutation the current in a short circuited coil should die down to zero value at about a uniform rate and should then rise to normal value in the opposite direction by the time the coil passes out from under the brush, as was illustrated in Fig. 12. This is the condition when no local currents are developed in the short circuited coils and this can only be obtained when the interpole e.m.f. at all times, balances the armature e.m.fs. in the short circuited coils.

Looking at the problem broadly, the resultant magnetic fluxes and e.m.fs. may be assumed as made up of two components which can be considered singly. One of these components is that which would be obtained *with the armature magnetomotive force alone acting through the various flux paths, including the interpole.* The other would be that which would be obtained with the *full interpole magnetomotive force alone*, the armature magnetomotive force being absent. Saturation is not considered in either case.

Considering the first component, due to the armature magnetomotive force alone, there would be the slot and the end fluxes with their short circuit e.m.fs., as already described, and in addition, there would be a relatively high flux, and short-circuit e.m.f. due to the good magnetic path furnished by the interpole core. In case the interpole does not cover the full width of the armature, or the number of interpoles is less than the main poles, there will also be some interpolar flux and e.m.f., as already described.

Considering the second component, *the entire interpole magnetomotive force* would set up a relatively high flux through the interpole magnetic circuit and a correspondingly high e.m.f. would be generated in a short circuited armature coil cutting this flux.

Digitized by Google

When these two components are superimposed, it is seen that the interpole flux due to the armature magnetomotive force is in direct opposition to that due to the interpole magnetomotive force and therefore only the e.m.f. due to their difference need be considered. As the interpole winding has the higher magnetomotive force, the resultant interpole e.m.f. is in opposite direction to the armature e.m.fs., and should be sufficient to neutralize them. This way of considering the problem avoids a number of confusing elements which would complicate the explanation, if given in detail.

In practice it is difficult to obtain exact equality between the interpole and armature e.m.fs. That due to the armature fluxes is generated in all parts of the coil including the end winding, while the e.m.f. due to the interpole flux is generated only in that part of the coil which lies in the armature slots. However, it makes no difference in what part of the coil the e.m.f. due to the interpole is generated provided it is of such value that it properly opposes and neutralizes the various e.m.fs., due to the armature fluxes. Therefore, in practice the interpoles need not have the same width as the armature core and, where space and magnetic conditions will permit, the number of interpoles can be made half that of the main poles.

According to the method outlined, the whole problem of the design of the interpole depends, first, upon the determination of the e.m.fs. due to the armature fluxes, and, second, upon the determination of such interpole flux as will generate an e.m.f. in the short circuited armature coils which will equal, or slightly exceed, the armature e.m.fs.

Interpole Calculations. Assuming that all the armature fluxes, except the interpolar, are unaffected by the presence of interpoles, the armature e.m.f. to be balanced by the interpole would be represented by the formula

$$E_c = \frac{I_c\, W_t\, R_s\, T_c\, \pi}{10^8}\left[c_1\,(L-L_1)\,\frac{2\,D\,p}{(0.25\,p+0.5)\,(\pi\,D-P\,p)}\right.$$

$$+c_2\left(\frac{4\,D}{p}\right)(0.9+0.035\,N)+$$

$$\left.c_3\,L\,\frac{1.33\,d_s+0.52+2.16\,s\,\sqrt{n}}{s}\right]+c_4\,\frac{2\,\phi\,N\,p\,T_c\,R_s}{10^8}$$

Digitized by Google

However, the flux above the slot, from the tooth top, is very considerably modified by the interpolar flux. In fact most of this should be omitted. It may be assumed that the flux across the slot, above the upper coil, simply "bulges" up slightly into the air gap, and the remainder of the usual tooth top flux is absent, except when the interpole does not cover the full armature width. Therefore, in the above formula, the term $L\times 2.16\sqrt{n}$ should be changed to $(L-L_1)\times 2.16\sqrt{n}$ and the term $\frac{1.33\ d_s+0.52}{s}$ replaced by $\frac{1.33\ d_s+0.7}{s}$.

Then, the corrected resultant of all the armature e.m.fs. becomes

$$E_c=\frac{I_c\,W_t\,R_s\,T_c\,\pi}{10^8}\left[c_1\,(L-L_1)\,\frac{2\,D\,p}{(0.25p+0.5)(\pi D-Pp)}\right.$$

$$+c_2\times\frac{4\,D}{p}\,(0.9+0.035\,N)$$

$$\left.+c_3\,L\,\frac{(1.33\,d_s+0.7)}{s}+c_3\,(L-L_1)\times 2.16\,\sqrt{n}\right]+c_4\times\frac{2\phi\,Np\,R_s\,T_c}{10^8}$$

In this formula

L represents the width of the armature core.

L_1 represents the effective width of interpole at the gap on the basis of the full number of interpoles.

$L-L_1$ is the difference between the width of the armature core and the interpole face. This term enters when the interpole is narrower than the armature core. When alternate interpoles are omitted and the remaining interpoles are of the same width as the armature core the conditions are practically the same as when the full number of interpoles are used but with their width equal to half the core width. Other combinations should be treated in the same way so that the above formula can be taken to represent the general conditions.

In practice it is desired that the resultant interpole e.m.f., and therefore the interpole flux, vary in proportion to the armature short-circuit e.m.f. which is to be neutralized. As shown by the last equation, this e.m.f. is proportional to the armature

Digitized by Google

current, except where there is saturation in the armature flux path, as in the case of magnetic bands over the core. Therefore the interpole magnetomotive force should vary in proportion to the armature current, neglecting core bands. In consequence, in practice the interpole winding is always connected in series with the armature winding.

The interpole magnetomotive force can be considered as made up of two components, one of which neutralizes the armature magnetomotive force, and the other component represents the ampere turns which set up the actual interpole flux. The first component will be referred to as the neutralizing ampere turns or neutralizing turns, and the other as the magnetizing ampere turns or magnetizing turns.

Let T represent the total interpole turns for one interpole,

T_i represent the total magnetizing interpole turns for one interpole.

T_a represent the total effective "armature turns per pole" $= \frac{\text{total eff. ampere turns of armature}}{\text{number poles} \times \text{total current}}$, and

I represent the amperes per interpole coil.

Then $I\,T_i = I\,T - I\,T_a$, or, $T = T_a + T_i$.

Let g = effective air gap per interpole.

B_i = flux density under the interpole, and

E_i = e.m.f. in an armature coil of turns T_c due to the interpole flux.

Then,

$$B_i = \frac{3.19\,I\,T_i}{g}$$

The e.m.f. due to one interpole is equal to

$$\frac{B_i\,\pi\,D\,L_1\,T_c\,R_s}{10^8}$$

Or, for two interpoles

$$E_i = \frac{3.19\,I\,T_i\,\pi\,D\,L_1 \times 2\,T_c\,R_s}{g \times 10^8}$$

Digitized by Google

This e.m.f. should be equal to the e.m.f. generated in the same coils by the armature flux, or $E_i = E_c$. Therefore,

$$\frac{3.19\, I\, T_i\, \pi\, D\, L_1 \times 2\, T_c\, R_s}{g \times 10^8} = \frac{I_c\, W_t\, T_c\, R_s\, \pi}{10^8}$$

$$\left[c_1 (L - L_1) \frac{2\, D\, p}{(0.25\, p + 0.5)\, (\pi\, D - P p)}\right.$$

$$+ c_2 \times \frac{4\, D}{p} (0.9 + 0.035\, N) + c_3\, L \frac{(1.33\, d + 0.7)}{s}$$

$$\left. + c_3 (L - L_1) 2.16 \sqrt{n}\right] + c_4 \frac{2\, \phi\, N p\, R_s\, T_c}{10^8}$$

In the second term of this equation $I_c\ W_t = I \times T_a' \times 2p$, where T_a' = total armature turns per pole, as distinguished from effective turns per pole T_a, and $T_a' = \frac{T_a}{1 - b\, p}$, where $b = \frac{B_i\, T_c}{W_t}$ as will be shown later under the subject of "Effective Armature Ampere Turns." Therefore, neglecting magnetic bands on the core, the above expression becomes,

$$T_i = \frac{T_a\, p\, g}{3.19\, D\, L_1\, (1 - b\, p)} \left[c_1 \times \frac{(L - L_1)\, 2\, D\, p}{(0.25\, p + 0.5)\, (\pi\, D - P p)}\right.$$

$$+ c_2 \times \frac{4\, D}{p} (0.9 + 0.035\, N) + c_3\, L \frac{(1.33\, d + 0.7)}{s}$$

$$\left. + c_3 (L - L_1)\, 2.16 \sqrt{n}\right]$$

$$T = T_i + T_a = T_a \left[1 + \frac{p\, g}{3.19\, D\, L_1\, (1 - b\, p)}\right.$$

$$\left(c_1 (L - L_1) \frac{2\, D\, p}{(0.25\, p + 0.5)\, (\pi\, D - P p)}\right.$$

$$+ c_2 \times \frac{4\, D}{p} (0.9 + 0.025\, N) + c_3\, L \frac{(1.33\, d_s + 0.7)}{s}$$

$$\left.\left. + c_3 (L - L_1)\, 2.16 \sqrt{n}\right)\right]$$

Digitized by Google

If the full number of interpoles is used, and each covers the full width of the armature, then $L-L_1=0$, and

$$T=T_a\left[1+\frac{p\,g}{3.19\,D\,L_1\,(1-b\,p)}\left(c_2\times\frac{4\,D}{p}\,(0.9+0.035\,N)\right.\right.$$

$$\left.\left.+c_3\,L\,\frac{(1.33\,d_s+0.7)}{s}\right)\right]$$

Therefore the total interpole turns for one pole are equal to the effective armature turns per pole multiplied by a constant which is a function of the proportions of the machine. However, this holds true only for the condition of no saturated path for the armature flux, such as magnetic bands.

The above formula gives the interpole turns for two interpoles acting on each armature coil. With but one interpole per coil the number of conductors per armature coil generating the interpole e.m.f. is halved so that the flux density must be at least doubled, and the effect of the armature flux in the interpolar space over the other half of the armature coil must also be taken into account. This can be done in the preceding formula by using the equivalent value of L_1.

With half the number of interpoles the effective gap length, g, will not be the same as with the full number of interpoles with the same mechanical gap, for the flux from the interpole may be considered as returning across the gap of the two adjacent main poles and the value of g must be increased to represent the total resultant gap.

Let g_e represent the effective resultant gap,
g_m represent the effective gap under the main poles,
A_i represent the area of the interpole gap, and
A_m represent the area of one main pole gap.

These areas can be derived from the field distribution or " field form " of the main and the interpoles.

Then, the effective resultant gap $g_e=g+\frac{A_i}{2\,A_m}\,g_m$, and this should be used instead of g.

With half the number of interpoles and on the basis of the interpole flux returning through the two adjacent main poles, it may be assumed that this flux weakens the total flux in one pole and strengthens that of the other pole a like amount. If

Digitized by Google

there is no saturation in the main poles or armature teeth under them, then no additional ampere turns, other than for the increased gap, will be required on account of the main poles carrying the interpolar fluxes. However, where there is much saturation of the main poles or teeth, then additional interpole ampere turns will be required, as will be described later in connection with effects of saturation.

Chord Windings with Interpoles. Chorded armature windings can be used with interpoles with satisfactory results provided the interpoles are suitably proportioned. There are apparently some advantages with such an arrangement, but there are also disadvantages of such a nature that it is questionable whether it is advisable to use chord windings with such machines, except possibly in special cases. When chorded windings are used with interpoles, the e.m.f. due to the armature flux is usually much smaller than with a pitch winding and thus fewer interpole magnetizing turns are required. Also, the effective armature turns which must be neutralized by the interpole are reduced somewhat, which also means a slight reduction in interpole turns. Against these advantages must be charged the disadvantage of a wider interpole face. This in itself would not be objectionable where there is space for such wider pole face, but if the space between the main poles must be increased it may lead to sacrifice in the proportions of the main poles or changes in the general dimensions, such that the result as a whole is less economical than with a pitch winding.

Effective Armature Ampere Turns. The term T_a representing the effective armature ampere turns should be considered, as the value of this term is influenced by a number of conditions, such as the number of bars covered by the brush, the amount of chording in the armature winding, etc. With a full pitch winding and neglecting the reduction in current in the short circuited coils, the magnetomotive force of the total armature winding is represented by the expression, $\frac{I_c W_t}{2}$, and per pole it is, $\frac{I_c W_t}{2p}$. However, when the brush spans several coils, so that a number of armature coils are short circuited at the same time, the average current in these short circuit coils should be considerably less than the normal value so that the effective ampere turns per pole is correspondingly reduced. Allowance must be

Digitized by Google

made for this reduction as it has considerable influence in determining the correct number of interpole turns.

On the basis of no local currents, the average value of the current in the short circuited coils is just half that of the work currents per conductor.

Let B represent the total number of commutator bars,
B_1 represent the number of bars spanned by the brush,
p_1 represent number of current paths, and
p number of poles.

Then, $\frac{B\ T_c}{p_1\ p}$ = total number of armature turns per pole, and

$\frac{B_1\ T_c}{2\ p_1}$ = number of turns by which the total armature turns per pole must be reduced to obtain the effective turns per pole, or,

$$T_a = \frac{B\ T_c}{p\ p_1} - \frac{B_1\ T_c}{2\ p_1}$$

$$B\ T_c = \frac{W_t}{2},\ \ldots T_a = \frac{W_t}{2\ p\ p_1} - \frac{B_1\ T_c}{2\ p_1}$$

Let $B_1\ T_c$ be represented as a percentage of W_t, or $B_1\ T_c = b\ W_t$

Then, $T_a = \frac{W_t}{2\ p_1\ p}\ (1 - b\ p)$

$$I\ T_a' = \frac{I_c\ W_t}{2\ p} = \frac{(I_c\ p_1)\ W_t}{2\ p\ p_1} = \frac{I\ W_t}{2\ p\ p_1},\ \ldots\ T_a' = \frac{W_t}{2\ p\ p_1}$$

Therefore, $T_a' = \frac{T_a}{(1 - b\ p)}$.

Chorded windings also have an influence on the effective armature ampere turns per pole. When the winding is chorded one slot, for example, then, in one slot per pole, the upper and lower coils will be carrying current in opposite directions and their magnetizing effects will be neutralized. In consequence, the total effective armature ampere turns are correspondingly reduced and this must be allowed for in determining the interpole turns.

Digitized by Google

Conditions Affecting Interpole Proportions. The foregoing formulæ have been based upon the use of interpoles of such proportions that the interpole flux varies directly as the magnetizing current and its distribution over the commutating zone is such as will give the proper opposing e.m.f. at all times.

However, the proportionality of flux to current can only be true as long as there is no saturation in the interpole magnetic circuit. Such saturation is liable to be found in practice and not infrequently it is quite a problem of design to avoid it within the working range of the machine.

Also, another difficult problem lies in so designing the interpole face that the flux distribution in the commutating zone is such that its e.m.f. will properly balance the armature e.m.fs. in the short circuited coils, especially as the latter are generated by cutting fluxes which may be distributed in a quite different manner from the interpole flux.

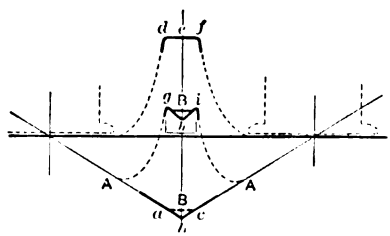


FIG. 21

Shape and Proportion of Interpole Face. As already shown, the effective interpole flux under the pole face is the resultant of the total interpole magnetomotive force and the opposing armature magnetomotive force. As the armature winding is distributed over a surface and the interpole winding is of the polar or concentrated type, the resultant magnetomotive force would normally be such as would not tend to give a uniform flux distribution under the interpole unless the interpole face is properly shaped or proportioned for such distribution. The conditions may be illustrated in Fig. 21. In this figure the lines *A A* represent the armature magnetomotive force, with a full pitch winding, and the brush covering one commutator bar. The heavier part of the lines *a b c* at the peak of the magnetomotive force diagram, represents the armature magnetomotive force which would be obtained under the interpole face, and also the flux distribution which would be obtained, with no interpole

Digitized by Google

magnetomotive force, and with uniform gap under the pole faces. In opposition is shown the interpole magnetomotive force and flux distributions *d e f* for corresponding conditions. The resultant magnetomotive force is represented by *g h i*, and with a uniform gap under the pole, the resultant interpole flux would have a similar distribution. Instead of this, either a flat or, in some cases, the reverse distribution is required, that is, with a slight " hump " in the middle instead of a depression. By properly shaping the pole face so as to give an increased air gap toward the edges, the flux distribution can be made practically anything desired. In some cases a relatively narrow pole tip with a very large air gap will give a close approximation to the desired flux distribution.

However, in practice the above distribution of the armature magnetomotive force is rarely found. The use of brushes which cover more than one commutator bar serves to cut off or flatten out the pointed top of the armature magnetomotive force diagram, as shown by the dotted line *B*, in Fig. 21, and thus lessen the depression at the center of the resultant magnetomotive force distribution.

As intimated before, this problem of proportioning the interpole face turns upon the determination of the armature e.m.fs. in the short circuited coils which have to be balanced by the interpole. If the different armature e.m.fs. are determined for the whole period of commutation and then superimposed, the resultant e.m.f. indicates the flux distribution required under the interpole. Usually the e.m.fs. due to the end winding, and to the interpolar flux, if any, will be practically constant during the whole period of commutation. If no local currents are present the e.m.f. due to the slot flux will also be practically constant, although it may be slightly reduced near the beginning and end of the commutation period. The sum of these e.m.fs. should therefore be practically constant over the whole commutation period and therefore, in a well designed machine, the interpole flux density should be practically constant over the whole commutation zone. As explained before, special shaping of the poles and pole face will be necessary, in most cases, to obtain exactly this proper flux distribution. Large interpole air gaps are obviously advantageous in obtaining such distribution. In fact, a very small interpole gap makes the determination of the proper interpole face dimensions very difficult in many cases. On account of the interpole usually covering less than two

Digitized by Google

armature teeth, the ordinarily accepted methods of determining the effective length of air gap under a pole will not apply, in many cases, which may lead to a slight error in the results. Practically the effective gap under the narrow interpole will usually be longer than determined by the ordinary methods. This partly explains the fact that, in some cases, an increase in mechanical clearance between the interpole face and the armature core does not require anything like a corresponding increase in the interpole magnetizing ampere turns. The effective interpole air gap increases, but at a much less rate than the mechanical gap.

The brush setting in relation to the interpole is of great importance. The point of maximum armature magnetomotive force is definitely fixed by the brush setting. With the interpole fixed in position, any shifting of the brushes backward or forward will obviously change the shape of the resultant magnetomotive force distribution under the interpole face and in consequence the flux distribution will be changed. With but one armature coil per slot and the brush covering but one commutator bar, good commutating conditions might be found over a considerable range of brush adjustment, by suitably varying the interpole ampere turns. However, with two or more coils per slot and with the brush short circuiting several bars, any marked change in the resultant interpole magnetomotive force and flux distribution will mean improper commutation for some of the coils. Proper brush setting is therefore of first importance.

It has been assumed in the foregoing treatment, that an exact balance between the interpole and armature e.m.fs. will give the best conditions. From certain standpoints, this is true, but in practice usually a slight excess in the interpole strength, or " over-compensation " of the interpole, as it is frequently called, is advantageous. Reference to Fig. 14 shows that in a machine without interpoles, and therefore without compensation, the current flowing between the brush contact and the commutator is crowded toward one brush edge, this being the edge at which the commutation of a coil is completed, that is, at the so-called forward brush edge. With over-compensation the opposite effect occurs—that is, the brush current density is below the average at the forward edge. This is, to a certain extent, a desirable condition. Also, if there is any saturation of the interpole circuit at overloads, the over excitation of the interpole winding can take care of the saturation ampere turns, so that

Digitized by Google

normal compensation can be obtained at considerably higher load than in a machine with no over compensation. Furthermore, over compensation is desirable on account of the effect of the resistance of the coils undergoing commutation, which heretofore has been neglected as being of minor importance. Such resistance tends to lower the current density at the middle of the brush contact, and increase it toward the brush edges. Over compensation will oppose this at the forward edge, but increase it at the back edge, which is less objectionable. Also, as shown in Fig. 21, there is liable to be a depression at the center of the interpole flux distribution, if the pole face is not properly shaped. This depression tends to cause higher current densities at the brush edges. Over compensation again tends to reduce this density at the forward brush edge. Thus there are several good reasons for slight over compensation, and practical operation bears this out, especially on high voltage machines, where the short circuit e.m.fs. average higher than in other machines.

Balanced Circuits. It has been assumed that the armature ampere turns per pole have been the same for all poles. This will be true for the usual two-circuit or series type of winding, or its allied combinations, but is not necessarily true of the parallel type of armature winding. In such a winding a number of circuits are connected in parallel at the brushes, and, unless ample provision be made for equalizing the different circuits, they may not carry equal currents at all times. As the resultant interpole flux and e.m.f. is directly dependent upon the opposing armature ampere turns, it is obvious that any inequalities in the armature currents would lead at once to incorrect interpole conditions. A poorly equalized parallel-wound armature might furnish conditions such that the interpoles cannot be adjusted for satisfactory operation. Also paralleling of the interpole windings, unless care be taken to insure equal current division among the circuits, is liable to lead to trouble.

Saturation of the Interpole Circuit. Heretofore the interpole turns T, as determined, have been only those required for forcing the resultant interpole flux across the effective interpole air gap, and nothing has been allowed for any turns required for magnetizing the parts of the interpole circuit other than the gap. Where such additional turns are required they must be added to the turns T, already determined.

Saturation in the interpole magnetic path is the principle cause for such additional turns, but saturation in the various

Digitized by Google

flux paths may occur in such a way as to be either harmful or beneficial, depending upon where it is located. Beneficial saturation may be assumed to be such as will reduce the armature short circuit e.m.fs., while harmful saturation tends to reduce the interpole e.m.f.

While the useful interpole flux passing into the armature may be relatively low—say one-fifth that required for saturation of the interpole material—the leakage flux between the interpole and the two adjacent main poles is often very much greater than the useful flux so that the interpole at the part where it carries the highest total flux may be worked up to possibly half saturation, or higher, with normal load on the machine. The interpole leakage flux is due to the *total ampere turns on the interpole*, while the useful interpole flux is due only to the magnetizing component of the interpole ampere turns, which may be as low as 15 per cent to 25 per cent of the total interpole ampere turns. The leakage flux is thus liable to be a high percentage of the total interpole flux.

While the ampere turns on the interpole will rise in direct proportion to the current, the effective magnetizing component will rise in direct proportion only below saturation of the interpole circuit. Any ampere turns required for saturating this circuit will be taken from the magnetizing component of the interpole winding. Therefore, when any appreciable saturation occurs, the effective magnetizing component will not vary in proportion to the current, and the interpole e.m.f. will not vary in proportion to the armature e.m.fs. As the magnetizing component of the interpole winding usually represents a relatively small number of ampere turns per pole a comparatively slight saturation in the interpole circuit may have an appreciable effect. It is therefore advisable to work at as low a saturation as possible in the interpole circuit so that practically no saturation occurs within the ordinary working range of the machine.

Where saturation occurs in any of the armature flux paths, as, for instance, with saturated bands over the armature core, the result of such saturation will serve to neutralize the effect of saturation in the interpole magnetic circuit. In other words, the armature e.m.f. will not rise in proportion to the current and therefore the opposing interpole e.m.f. does not need to increase in proportion either.

The principal source of saturation in the interpole circuit lies in the magnetic leakage from the interpole to the adjacent main

Digitized by Google

poles. Serious trouble has often been encountered by not making due allowance for such leakage. However, there may be other causes for saturation. When the full number of interpoles is used the interpole magnetic path or circuit is independent of the main pole magnetic circuit, except in the yoke and in the armature core below the slots, as indicated in Fig. 22. In the yoke it may be seen that the interpole flux is in the same direction as the main flux at one side of the main pole and is in opposition to the main flux at the other side. The same is true in the armature core. Therefore the interpolar flux tends to reduce the flux in one part of the yoke and tends to increase it in the other part. If the saturation in these parts is relatively low, then the magnetomotive force required for forcing the low and the high fluxes through the yoke will be but little greater than if these fluxes were equal. However, if the yoke is highly saturated the increase in ampere turns required for the high part much more than offset the decrease in ampere turns for the low part, so that, as a result, additional ampere turns are required for sending the interpole flux through this path. The interpole ampere turns therefore must be increased on this account, when the saturation is high. The same condition holds for the armature core.

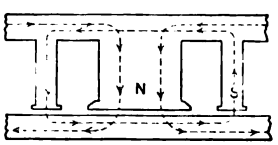


FIG. 22

A similar condition occurs where half the number of interpoles is used and when there is much saturation of the main pole and the armature teeth under it, as already referred to. This condition requires additional interpole ampere turns.

In practice, with the ordinary compact designs of direct current machines, it is usually difficult to keep the total interpole flux as low as one-third that which gives any material saturation and, not infrequently, it is much higher than this. Therefore, by direct proportion it might be assumed that such machines could carry only double to treble load without sparking badly. However, the resistance of the brushes, etc., will be of such assistance that relatively higher loads may be commutated reasonably well. For instance, with the interpole worked at about half saturation at normal load, the machine may be able to commutate considerably more than double load without undue sparking. It is also of material assistance, where heavy overloads are to be carried, to over-excite the interpole winding, that is, to make the magnetizing component somewhat greater

Digitized by Google

than required at normal load, as described before. In this case, at light loads, the interpole e.m.f. exceeds the armature e.m.f. a certain amount which is taken care of by the brush resistance as local currents will be less harmful when the work current is low. As partial saturation is obtained at overload, the two e.m.fs. become equal but at a higher load than would be the case without over-excitation of the interpole.

Commutating Conditions on Short Circuit. When a direct current generator is short circuited across its terminals, either through a low external resistance or without such resistance, a current rush will occur which will rise to a value represented approximately by the generated e.m.f. divided by the resistance in circuit. This current rush is only of short duration as the excessive armature current will react to demagnetize or " kill " the field. If the short circuit is without external resistance the current rush may reach an enormous value as the internal resistance on large machines is usually very low. This means that currents from 25 to 40 times full load may be obtained on " dead " short circuit. Experience shows that under such current rushes, any kind of direct current machine will tend to flash viciously at the brushes.

By the preceding theory and analysis a rough approximation to the commutating conditions on short circuit can readily be obtained. Assuming an interpole machine, the following conditions will be found:

1. The interpole will be highly saturated so that it is of little or no direct benefit.

2. The slot flux will rise to such a value that the armature teeth in the commutating zone are practically saturated.

3. There may be some interpolar flux from the armature, as the high interpole saturation may allow this.

4. The armature end flux, with the exception of that part due to magnetic bands, will rise practically in proportion to the current.

The following short circuit e.m.f. conditions will be obtained:

1. There will be possibly a slight e.m.f. due to the armature interpolar flux.

2. There will be an e.m.f. due to the tooth flux which is almost as high, per conductor, as could be obtained by a conductor cutting the flux *under the main field at no load*, for saturation of the armature teeth may be assumed to be the limit in both cases.

3. There will be an e.m.f. due to the end flux which may be 10 to 20 times larger than at normal full load.

Digitized by Google

Therefore, the total e.m.f. in the short circuited coil due to cutting the armature flux on dead short circuit may be higher than would be obtained *if the brushes were shifted at no load until the commutated coil lies under the strongest part of the main field.*

As very few machines of large capacity would stand this latter condition without flashing, it may be assumed that they would be no more able to stand a dead short circuit without flashing. In fact, 8 to 10 times full load current will make an interpolar machine of normally good design flash badly, as it is impracticable to make an interpole of the usual type which will not saturate highly at 8 to 10 times normal current.

If, however, the interpole is combined with compensating windings in the main poles, the interpole leakage may be made so small that comparatively low saturation is obtained normally in the interpole circuit. In such case the interpole may be effective with heavier currents and the flashing load may be very much higher than with the usual type of interpole machines.

Conclusion

The foregoing is a general presentation of the problem of commutation, which is admittedly crude and incomplete in some points. In particular may be mentioned the part describing the action of local currents. Also, the method of considering the resultant action in interpole machines as the superposition of two components does not tell the whole story, but the actual analysis, in detail, of a number of these phenomena would be so confusing and complicated that a general physical conception of what takes place during commutation would be lost. In the ultimate analysis it will be found that a number of the methods described are, in reality, simply illustrations of the conditions of commutation rather than an analysis of the conditions themselves. However, the method as given throws light on many things which take place during commutation. It also includes a number of conditions which are not covered in the usual methods of dealing with this problem. For example, the number of commutator bars spanned by the brush is an important element in this method of handling the problem, whereas, in many former methods, this point was either omitted, or treated in an empirical manner. In this method the results obtained would be very greatly in error if the brush span were not included.

Any theory or method of calculation is open to question until it has stood the proof of actual test. In consequence, the above

Digitized by Google

method has been tried on a very large number of direct current machines, including high speed direct current generators, direct current turbo-generators, direct current railway motors of all sizes, moderate- and low-speed generators of all capacities, industrial motors of various designs including adjustable speed motors and machines with half the number of interpoles. In those cases where the actual test data of the machines was very accurately obtained, the agreement between the tests and the calculated results by the above method was found to be close. In fact, the method in some cases indicated errors or inaccuracies in the test results. In a number of cases of early interpole machines there was considerable disagreement between the results of the calculation and the actual test, but, in many of these cases, later experience showed definitely that the proper interpole field strength or proportions had not been obtained in the actual test or that the proper brush setting had not been used. These cases were thus, to a certain extent, a verification of the method, for in general the greatest discrepancies between the calculated and the test results corresponded to the machines which eventually proved to have the poorest proportions or adjustment.

This theory of commutation looks complicated and cumbersome in its practical application, but it should be understood that it is, in reality, an exposition of a general method from which special and simpler methods may be derived for different types and designs of machines. It indicates plainly that the problem is so complicated that no simple formulæ or methods of calculation can be devised which will cover more than individual cases, and that such formulæ, if applied generally, will lead to error sooner or later. If, however, the general derivation of such simplified formulæ is well understood, then they may be used with proper judgment and with much less danger of error in the results. It is evident, from the general analysis, that the whole problem must be handled with judgment, for new or different conditions are encountered in almost every type of machine.

A great many problems, closely allied to that of commutation in interpole machines, have not been considered, because some of them represent special cases of the general theory, while others are somewhat outside the subject of this paper. Of the former class may be mentioned, commutation of synchronous converters, machines with distributed or true compensating

Digitized by Google

windings, the so-called " split-pole " converter, and the commutator type alternating current motors, etc. In the latter class may be included such problems as the effect on commutation of closed circuits around the interpoles, losses due to commutation, current distribution at the brush contact, etc. Some of these subjects were included in this paper as originally prepared, but on account of its undue length they had to be omitted.

Digitized by Google

DISCUSSION ON "SOME RECENT DEVELOPMENTS IN RAILWAY TELEPHONY," LOS ANGELES, CAL., APRIL 27, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions)

Kempster B. Miller: The matter of railway train dispatching, discussed by Mr. Brown in his paper, is one of great importance, not only to telephone men, but to railway people and the public at large. There is an impressive mileage of railroads, important railroads, that are now being operated by telephone rather than by the telegraph, and this fact is surprising to those who have not watched and been in close touch with the development of this branch of telephony.

An interesting thing in the discussion of the power transmission papers, day before yesterday, was that some companies had seen fit to build a separate pole line for the telephone circuit, distinct from the power transmission line. That is not because it is impossible to put telephone wires on transmission poles and get fairly good service, but in order to effect an extra precaution to insure telephone transmission at the time it is most needed. In many cases that is not done—I should say in the great majority of cases. Now, if the power transmission companies are, for added security, willing to build a separate pole line for telephone circuits when they already have a high grade line, the question naturally arises in my mind in regard to this telephone railway train dispatching, is it wise for the railroads to load up the talking circuit with the selective ringing apparatus? I see no reason for even suggesting the building of another pole line in the case of railway circuits; but it does seem to me that in many cases the building of a separate copper circuit, or iron if the conditions warrant iron, for operating the selective bells would be warranted. This separate circuit for the operation of the selective bells on the dispatching system, would prevent loading down, with ringing apparatus, a circuit already overloaded with a multiplicity of bridged talking circuits. I understand that some railroads are doing it but that many others have refused to spend the necessary amount of money. In view of the extreme importance, particularly from the standpoint of the safety of the public, I think this phase of the subject worth discussion.

L. B. Cramer: I have not much to say in regard to this paper, as the experience that I have had with the system is not of very long duration, because the line was not entirely completed when I left to come here; but I have a few questions to ask Mr. Brown.

One thing that I do not entirely agree with Mr. Brown in is his statement that the "arrangements permitting the signaling of stations without interrupting conversation results in a saving of a considerable amount of time."

So far as my observation has been concerned, that seems to be more of a salesman's talking point than a reality in operation. Perhaps you might be able to talk while the man is signaling,

Digitized by Google

but once he is finished and the man at the other end has an opportunity to say, "What was that?" and then all of it has to be repeated. Perhaps I have not had enough experience or perhaps our line is not in proper tune to take care of this, but at present that seems to be one thing that does not work out as it is supposed to—that is, the way the company represented the apparatus said it would work.

I have also noticed, in regard to the ringing of the bell at the station called, the sending keys are made of such a size, that if they were made a little larger they would not make a cabinet of extremely large dimensions and the amount of space that can be given to them would then be enough to produce a ring long enough to call the operator. I notice our dispatcher often calls a second and even a third time. In case of substations, where the bell is mounted on a booth, there being some noise in the machines, we have an auxiliary bell that makes plenty of noise and the substations are the stations from which we get the best responses.

In regard to the switches, which have one position for receiving and one for transmitting I have already thought of making some changes in the apparatus because in stations where we have a set that is mounted on a desk, about the second or third day after the telephone is in operation the agents get a ruler or a stick and plug the button. This, perhaps, could be made a subject of discipline and, taken care of in that way, and you could get the result which you are supposed to get by being able to hear better by leaving the button in normal position and only press the button in when you are talking. The agent and operator will do these things and when there is a train coming, or anyone whom they think will see it, they will take the plug out; but ordinarily, they will leave it plugged up so when they want to O. S. a train, they will not have to work the plug.

Another thing that I would like to ask Mr. Brown is in regard to the retardation coils. We made some tests on another railway where their telephone circuit is carried on the same poles as the 33,000-volt transmission system. We made tests of two different companys' apparatus. In the type of apparatus which the author describes I notice they used three retardation coils. On that particular test the man had about 80 miles of telephone line and he was unable to produce results to any great extent, while another company's representative with apparatus similar to this one, but on which he used only one retardation coil, he was able to handle his calling without any trouble and the transmission seemed to be first class. Now, whether there was something in the atmospheric conditions at the time when these different tests were made, or whether it was just a case of some operator's interfering—that is one thing that some of the telegraph operators will try to do. If they know you are trying out a telephone which will do away with their job as telegraph

Digitized by Google

operator, they will resort to almost any means to put the telephone out of commission. We have no trouble in using the telephone in connection with the telegraph, where the telephone is used mostly for handling messages pertaining to freight shipments and dispatching power.

Ralph Bennett: This system was offered to me about two years ago, for use in connection with the transmission line telephone. We did not adopt it. There were a number of questions that came up that the manufacturers could not answer. We have on our telephone line a pressure of about 2,000 volts to the ground, and 600 micro-amperes unbalanced current flow. The line is noisy. When we had trouble on the line we would have additional voltages. The manufacturer could not state how we could repair his sets with the men we had. He could not state definitely his apparatus would satisfactorily select in the presence of those large currents under heavy pressure in this transmission line. I would ask Mr. Brown whether these things could not be handled as the securing of a telephone which will call and select stations for transmission line work is very important.

Ralph W. Pope: Mr. Chairman, there does not seem to be anyone here to take up the telegraph operators' view of the situation.

Now it has been my experience in my fifty years of knowledge of the Morse telegraph, that the people who do not understand it and work it don't appreciate what a beautiful and simple method it is of transmitting communications. It may be of a little bit of interest—add a personal touch—if I tell you that years ago, having some fifty pages of what would now be fifty pages of typewriting, to copy, and several manifold copies to be made, that Mr. Edison, my brother, one other operator and myself took turns in sending and then copying down from the sounder. We did that because it is an easier way to copy it from the sounder than by looking from one page to another. You simply write and the words go in your ear and go out of your pen or pencil onto the paper and that becomes so automatic that in the course of receiving a long press report, as we did during the Civil War, the operator was obliged to take a bunch of carbon paper and change the sheets at the bottom of each page so as to pick up the work when a new batch of sheets were ready, and this involved keeping behind about fifteen words, behind the sounder, and it took all of the next page to catch up with the sender. I am giving you this as an instance of what the telegraph system really is. Now, we take the way station of a railroad and the operator always has to look out for baggage and various things around the place and wherever he is in that room, no matter whether he is called or not, he knows what is going on over the wire. Of course, if he is called, he is obliged to answer. As an instance of what an operator can pick up in that way, I went down from Great Barrington, to Sheffield, expecting to ride

Digitized by Google

back on the passenger train. It was bulletined on the telegraph board " No Report ". I thought I could get to Great Barrington for dinner but I could not find out whether I could and I sat there waiting to get my lunch, growing hungrier all the time. Meanwhile I heard a message going over the line that the train had been delayed, and that they would meet at Canam somewhere below, and so on; and I figured out it would be an hour and forty minutes before the train would be along. So I went to the operator and said, " How late is your train going to be?" He says, " I don't know; I have had no report of it." I said to him, " According to the information I received, they are going to meet at Canam and it will be about an hour and forty minutes wait, and I thought I would have time to go out and get my lunch." Well, he said, " you are a pretty good guesser."

Perhaps what we may call that particular qualification of the telegraph would not appeal to the railroad management, that a man outside could find out how the trains were running. The point I am endeavoring to make in this is, that the Morse system is available to that man wherever he may be walking around the place. He has not got to go and answer a call and put a telephone up to his ear and drop everything else; but he takes that incidentally with his other work. That is simply one of the features of the Morse system that appeals to the railroad telegraph man. You must remember also that a great many of the men who are in active management are practical Morse operators, have grown up with the system, and know what it can do. This question has been discussed before several conventions of the Railway Telegraph Superintendents, and the probabilities are that I shall have occasion to discuss it at their next convention in June. So you will see that there is another side to the question. Here you have a railroad force developed from telegraph operators who are familiar with a system of this kind, and it is the simplest and best thing that appeals to us in carrying on this work. Were a sounder there, I can receive a message sitting here, and I don't have to hold anything to my ear at all. I simply sit down and write from it, and where a man has grown up with it and is familiar with it, he never can get over that love and appreciation of the simplicity of the Morse telegraph system as known to the one who has practiced it, although it is now thirty years since I have done so.

K. B. Miller: I can add my little personal touch there, although a much less skillful operator than Mr. Pope was, and having no right to claim to be an old timer, that it is much easier for me, or would have been in days gone by, to have written down matter taken from a sounder than to get it by telephone. Mr. Pope's remarks suggest a distinct need in railway train dispatching. Some way may be evolved of relieving the despatcher, who is a rather important man, from wearing a harness—I refer to the head telephone. They don't like to do it. The loud speaking receiver has been proposed and tried out rather care-

Digitized by Google

fully, and so far as I know has failed. One very ingenious way has been proposed and tried, but has not met with good results owing to poor articulation. It is to use at the despatcher's station a telephone repeater so that the feeble incoming currents could be magnified to produce loud talk in the receiver, and thus relieve the despatcher of the necessity of listening to a receiver held to his ear. This produced plenty of noise but it is articulate speech rather than noise that railway train despatching needs.

C. F. Elwell: In glancing over the paper, I was struck by the last paragraph, "Although the telephone has been in use on railroad divisions for less than four years, it has proven to have a great many advantages over the telegraph." I only intrude on your time to tell you the little experience I have had with the thing 10 years ago in Australia. I went out there to put in block signal systems, and they were already then using the telephone for all of their work. They had a system there in circuits of about 100 miles, just a parallel system magneto and code of signals for ringing. The signals were usually Morse letters, dots and dashes, and they seemed to have very good satisfaction with the phone. They had no telegraph instruments in the office at all. In the matter of calling up, we found lots of times that at certain stations it was almost needless to call. All we had to do was to take the phone off and say, "Are you there?" Those men used to sit with the receiver glued to their ears so they could know all that was going on between all the stations. I just mention this in passing to show you that the matter is a good deal older in other countries. I don't know how old it is there, but I know this was in 1901—ten years ago.

Ralph W. Pope: I might add to my remarks, that the conditions which I spoke of in regard to the railroad service have changed very much within my recollection. When I entered the service, the station agents knew nothing about the telegraph, so in order to have telegraph facilities, the railroad was obliged to have an operator in addition to the agent, so that today we have this different state of affairs where the telegraph operator has grown up to be the agent, and the agent therefore is not necessarily obliged to have an operator at his station, on his staff. This means nothing in large stations where they have several employees, because there is enough work to keep the operator busy; but in small stations it simply means that one man, by his knowledge of telegraphy, his knowledge of railroad work, can be the whole thing.

S. G. McMeen: Some gentleman asked the author the question whether systems of this kind could be used on telephone lines associated with transmission lines? If Mr. Lisberger is present, he can speak of a system of this kind which is in service with a transmission line and distributing system, all within one system, but which has in it all the elements which would result in a long transmission. He could give practical information

Digitized by Google

on a selector line. As to the thought, the author may criticize my asking the question, in this particular case in which Mr. Lisberger is familiar, as it connects stations which he operates, the only difference between a long transmission line and his case, is in the line. It is not in the apparatus or in the operation of the apparatus. Therefore, the problem becomes this: If with the system he has he had a longer line and a greater exposure, he would have a practical answer to the question which has been answered. Now, if the lines were longer and had a greater exposure, what new difficulties would be introduced? Only these: that the greater exposure might make that line noisy if it were not well balanced. That is to say, the only features which might make it unsuccessful in that case would be line features. And if we can build a telephone line which will be quiet during reasonable perfection of the telegraph line which it accompanies, then we can have good service over it. Such lines as that are operating every day successfully. So far as the telephone line and telegraph line are in normal condition, then successful operation ensues. There is nothing in the selective apparatus or in the special features of the dispatching circuit which would cause that line to be less easily perfected and operated than a telephone bridging apparatus. Therefore I would like to hear Mr. Lisberger speak of this line as to its automatic and rapid selection, which represents everything that is of a new character as to which the gentleman asked.

Ralph W. Pope: I wish to express my appreciation especially of this telephone session. Perhaps the Institute has been criticized more severely by some of its members upon this telephone question than any other branch of electrical engineering, as to why it was not giving more attention to the telephone. As you know, that means, why have we not had more telephone papers? I think that this question has been answered—that for the first time we have had Mr. McMeen as an active member of the Telephony and Telegraphy Committee on the Pacific Coast where both great systems of telephony are in operation. We have had Col. Reber as chairman of that committee and he has taken a great deal of interest in this subject and has added to it a great deal by reason of his great familiarity with it due to the position he holds in the Signal Department of the Government.

I must admit I was surprised at the number and quality of this group of telephone papers. I think that great credit is due to Mr. McMeen for his activity in getting them together. I wish to say further that we have had telephone papers before but they never have been discussed so thoroughly by people who were familiar with the various systems in use. This meeting, suggested by Mr. McMeen, for this year, to my mind marks an epoch in the development of the Institute's treatment of telephone engineering. It will be up to us, wherever we may meet hereafter, to endeavor to attain this standard.

Digitized by Google

J. A. Lighthipe: I have been out of the telephone work a long time but I feel like our beloved Secretary, Mr. Pope, no matter how long he is away from the old original Morse, he still loves it. It is the same way with me in the telephone work. I still love it and try to follow it.

In the old days of the telephone, when it first started, the best receiver we had was what we called a crown receiver. It had six magnets screwed on the back of a handle, and was found to be wonderfully improved by dropping off five and using one. Then the only carbon buttons that were used in the country—we must give Mr. Edison the credit of being the first man who really used carbon buttons on his transmitter—were made in a small shack in the rear of the laboratory at Menlo Park. Mr. Edison could not use commercial lamp black for making the buttons so he made it by smoking kerosene lamps. He had about fifty of these lamps with a V cut out of the center of the wick to make it smoke, and kept the chimneys turning around until they were full of lampblack which was scraped out later.

The smoking process was attended to by an old Irishman who was possessed of great skill in picking up a lamp when it was on fire and throwing it out of the open door. The old transmitter was made of two brass buttons the faces of which were covered with platinum, and a carbon button pressed in between them. At that time it completely revolutionized the telephone business. It was the first time we could talk any distance at all and it really opened the commercial field for telephone work.

Mr. Edison, at that time, was quite deaf. Today he is even more so. It is very hard to talk to him. He could hardly hear the old Bell telephone; even with the carbon transmitter. It was hard work for him to understand what was said at the other end. He therefore tried to invent, or did invent a loud speaking telephone. Very few of you have ever seen one, although they are very simple to make. They consist of a chalk cylinder made by pressing precipitated chalk and afterward turning it down to one inch in diameter. Upon the surface of the cylinder rested a small stylus tipped with palladium. The end of the stylus was fastened to the center of a mica diaphragm. This cylinder was continually rotating and when the telephone was properly adjusted the sound coming out of the receiver was considerably louder than that going into the transmitter; you almost invariably had to pull your ear away when you were talking into it. I don't know that the principle of that telephone has ever been thoroughly understood. When a current passes through the stylus to the cylinder, the tension is released. In turning the cylinder the diaphragm was continually pulled in one direction. As the different waves passed through the chalk the stylus would slip so that the mica diaphragm in the receiver would practically duplicate the motion of the diaphragm in the transmitter. This telephone lasted only a few months. I don't think it was ever introduced in this country. They tried to put

Digitized by Google

it in use in London, but today it is simply laid aside as one of our curiosities.

When the Blake transmitter came out, it was the starting point of all our telephones. It was adjusted so beautifully that you could stand off five or six inches from the transmitter, whereas before you had to talk right up close. The old Blake transmitter probably has done more good towards the univer sal adoption of the telephone system than any one thing.

In closing I will simply state that I am very very glad to meet the engineers of the telephone convention here. I have followed up, as far as I could, in my crude way; what wonderful improvements they have made. Mr. McMeen was kind enough to show me the first automatic machine I ever saw. That was at Fourth and Market Streets in San Francisco right after the fire. I was simply astonished at the magnificent mechanism of that machine. It was almost human in its hunting up a free trunk, selecting the number, either getting the subscriber or answering back that it was busy. I had no idea up to that time what a wonderful development had been made.

S. J. Lisberger: The telephone system which we have in use in San Francisco is not in any wise connected with a long distance transmission system. The system of the San Francisco Gas & Electric Co. is that used by most companies in city distribution work, namely, a main generating station with a number of substations. In San Francisco we have nine substations and one generating station. We were confronted with the problem of quick despatching between substations in times of trouble. Our ordinary system of telephone communication is a central board in our main office building on Sutter Street, from which point lines radiate to stations and substations. There is always an operator at this main switchboard, day and night. It was therefore necessary if an operator at substation B wanted to get into communication with substation C, to get into communication with the main office first. If we lost a bank of transformers, or a small section of line came down, or in the event of serious trouble to a substation, such as we had after the San Francisco fire, there would be so many calls coming into the main board, that the operator could not give time and attention to the substation calls, and very often we found that if one substation could only get into communication with another substation the trouble could be very quickly remedied, whereas we were often delayed five or ten minutes. The solution of the problem was to get quick communication between substations. The system we finally adopted was worked out for us by Mr. McMeen and was an automatic system. We had objections to an intercommunicating system of our own due to the fact that it must be attached to our poles or in our conduits and that was open to the objection that if we had trouble it was entirely possible to lose our entire communicating system. The wire system, belongs entirely

Digitized by Google

to the Home Telephone Company; is carried on their own lines, in their own conduit systems, and is entirely independent of the system we have in operation; all that is necessary for one station to get another is merely to turn the selector switch to the required numbers—it takes three different movements to call; the system starts with 721 and runs to 730. I have shown to several of our visitors the time it takes to call a station, which is about 9 seconds.

It is very often necessary for one station to talk to three stations, or four stations at a time and we have what we call a master switch and one station can get every other station on the line by working that mechanism. Mr. McMeen went further to help us in the problem, (but we did not take his further suggestion, not because we did not want it, but because we could not afford it) wherein he offered to give us a signal board which would show, by means of lights when we were calling a series of stations, whether they answered or not. If station C called stations B, E and F, under our present system, station C would ring first station B, then station E and then station F. All the stations have orders to wait on the line until someone talks. Mr. McMeen designed an indicating board that would quickly indicate who was on the line, would show when B was on the line and next E was on the line and next F was on the line. That was very nice but involved some financial difficulties that we did not care to meet. Otherwise, in all matters, it is most satisfactory to us.

S. G. McMeen: I might say that although Mr. Lisberger spoke of this as automatic, it is not an adaptation of the automatic station equipment. It is an adaptation of the railway dispatching apparatus. The devices used are not telephone exchange selectors, but railway telephone selectors, although instead of working the telegraph key, the operator works it with a round, automatic station dial. This is merely used as an interruptor for the calling impulses.

Gregory Brown: Mr. Miller brought up the question of separate signalling circuits. There is one type of selector, so far as I know, that uses three wires—one for signalling and two for talking. That has not been very extensively used. When you consider the impedance of the selectors across the line, it hardly seems necessary to consider that line very heavily loaded as far as transmission is concerned. For that reason, I do not believe it would be necessary to have a separate signalling wire. Selectors are also being experimented with now that have an impedance of something over 600,000 ohms. These selectors contain advantages due to that high resistance, and if they are used, it certainly would not be necessary from a transmission standpoint to have an extra signalling wire.

Mr. Cramer seems to have had quite a few troubles. The first he mentions is that he does not find it feasible to signal and talk at the same time. I have been around pretty nearly

Digitized by Google

all over the country on the various roads, and this is a complaint that is practically new to me. In some cases I have found this to occur, but on investigation we generally find that there is some trouble with the despatchers apparatus. One of the troubles that occurs perhaps more than any other and causes these results is the breaking down of the condensers at the dispatcher's office. These would not round off a sending wave to such a great extent.

The length of ring has been criticized—the length of ring at the station. I have gotten around that, where they want a longer ring, by installing a strap key at the dispatcher's office. This key is wired in a parallel with the automatic keys, and if the dispatcher, for any reason wants the bell in the station he is calling to ring longer than would ordinarily be the case, he turns the calling key of that station, and when he hears the answer back he merely presses down the strap key. There are various other modifications of selector arrangements which permit the bell to ring in the substation until the substation operator presses a button. In fact, most any kind of service can be given, according to what the particular railroad wants, but, as a general thing, most of them are satisfied with a certain length ring, about a second and a half, uniformly in all stations.

Another trouble that was experienced was that the agent sticks a toothpick or something in the push button and holds it down. The obvious plan to pursue there is to fire the agent; and this has been done in a great many cases, especially when the telephone was first used on railroads. As has been mentioned by several of the speakers, the operators bucked a good deal at the introduction of the telephone, their idea being that they probably were going to have their salaries reduced, or some of them would lose their jobs. It is not the policy of large railroads to put men out of employment except in very extreme cases, and if the introduction of the telephone permits offices to be closed, or forces to be reduced at certain points the men as a rule are taken care of in some other position.

A test on a 33,000-volt line was mentioned in which the apparatus of two manufacturers was used. It seems to me that the telephone apparatus used in this test is at least very similar among manufacturers, that is, the large manufacturers, and that it hardly could be a question of quality of apparatus to show up in the way that was indicated; that is, according to the statement that was made, I gather that one of them failed completely, and the other one gave good satisfaction. It seems to me there must have been another factor that entered into those two tests that caused that great difference, because the transmitters and coils, and so on, are very nearly similar insofar as their excellence is concerned.

Mr. Bennett spoke of calling and selecting on transmission lines. Mr. McMeen answered this question about the only way it can be answered, I guess, and that is with proper trans-

Digitized by Google

positions of your line if you get a quiet telephone line you can do anything with it in the way of talking and selecting.

Mr. Pope brought up the point in favor of the telegraph in that you could hear the telegraph when you were at some distance away from the instrument, whereas in the telephone you have to have the instrument up to your ear. About two months ago I conducted a trial installation down on one of the Pennsylvania lines, using a new type of loud speaking receiver. Criticism has been made of the telephone when used on a railroad division that it was all right for every purpose except blocking, and that for this purpose it was not as quick as the telegraph, and this criticism seemed to be more or less justified. The reason that this criticism was made was that in telephone blocking it is necessary for the operator to ring up another operator and then go through the motions of putting the receiver on his head and talking with him, whereas with the telegraph he merely ticks off what he wants to say and it is done. And that was the reason for the development or the experiments with loud speakers of various kinds and the attempt to develop a good one.

There has been considerable work done on this, and although it has been comparatively easy to get up a loud speaker for blocking—one that was plenty loud enough—still the articulation was not what it should be. This blocking service represents an ideal condition for loud speakers, because the lines are extremely short and are not loaded, and you can take full advantage of all the energy coming out of the transmitter. This installation was put in in three or four of the towers, and was left in for about ten days. During that time it was used exclusively by the operators for blocking trains, and in fact, they much preferred to use these speakers because the work was easier for them. They were then taken out merely to put them in in a better shape the next time as far as mounting is concerned, making it more convenient for use, and also to employ a busy test by means of a buzzer that had not been taken care of in the first installation. It is intended to use or experiment with this same type of receiver for dispatcher's use, and there will shortly be some trials in that field.

Mr. Elwell spoke of a train dispatching line being in use in Australia in 1902, I think it was. In the first part of my paper I mention two or three instances of the early installation of telephones on a train wire. All these installations used code ringing, and for that reason they were not very successful. There was too much of a load on the dispatcher. I think the first one used in this country was in 1883, which is probably before the one mentioned by Mr. Elwell.

I think there is no doubt that the telephone has proven its case on the railroad and I mention in the paper quite a few advantages of the telephone over the telegraph and I can probably mention quite a few more, and anybody who thinks of the matter can easily see that there is no question but what the

Digitized by Google

telephone does have advantages over the telegraph. Mr. Miller, I believe, raised the point about the distinctness with which the intelligence could be transmitted over the telephone—that is, where train orders, important orders regarding train service in which human life is risked—the distinctness with which they could be heard. Now, in sending out orders, the various railroads have standardized, in their telegraph methods, and they have also adopted practically the same scheme when they shifted over to the telephone. In sending out an order the despatcher rings the various operators and they will come in and then he states a certain number, 31 or 23, or whatever it is, which indicates the type of order he is to give and he starts to give his order and as he gives his order he writes it down himself so as not to give the order faster than the operator can take it down. As the dispatcher writes the order when he comes to the name of a town or any figures whatever, engine numbers or anything similar, or the time, besides speaking it in the ordinary manner, he spells it out. After he has completed giving the order the operators in their turn repeat this back to him and as each operator repeats it back to him the despatcher underlines the word repeated, so if there are three operators repeating the record of the order would be in the desptacher's book—it would have three underlines under each word which was repeated, which would supposedly prove it had been repeated by three operators.

Digitized by Google

DISCUSSION ON "CISOIDAL OSCILLATIONS," LOS ANGELES, APRIL 25, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

C. L. Cory: In order to obtain a physical and in fact practical conception of the results obtained by Mr. Campbell as treated mathematically in his paper, it may be well to consider one of the comparatively simple conditions existing in a circuit containing resistance R and inductance L, there being applied to this circuit an electromotive force having an instantaneous value e, which varies with time t.

In such a circuit the equation which expresses the value of the instantaneous electromotive force, interpreting the equation physically rather than expressing it mathematically, is that the instantaneous electromotive force e applied to such a circuit is expended in two ways; first, to overcome the resistance of the circuit or $R\,i$; and second, to overcome the electromotive force of self-induction in the circuit or $L\,\frac{d\,i}{d\,t}$.

Mathematically such an equation would be as follows:—

$$e = R\,i + L\,\frac{d\,i}{d\,t}.$$

Even with such a comparatively simple equation it can not be solved to give us practical results unless we know or assume the law by which the electromotive force varies with time. However, practically we assume a sine function of the time, and we therefore have: $e = E \sin w\,t$, in which E is the maximum value of the electromotive force and w is equal to $\frac{2\,\pi}{T}$, where T is the time of a complete period.

Instead of having circuits containing resistance R and self-induction or inductance L, only, as we well know, we may have a circuit which contains resistance and electrostatic capacity, or a more complex circuit which contains resistance, inductance and capacity, or a still more complex condition of the circuit or network which contains resistance, inductance, capacity and mutual inductance.

The mutual induction in a circuit can, however, very readily be represented by an equivalent self-induction.

If a variable electromotive force is applied to any of the above circuits and we assume that such electromotive force varies as a sine function of the time, and we solve for the practical values or virtual or effective current and electromotive force, as well as equivalent resistances, reactances and impedances, we get what mathematically is known as the constant of integration. It is this constant of integration which Mr. Campbell has so beautifully and completely treated in his paper. Let us discuss from a strictly physical standpoint this constant of integration.

In an ordinary alternating current circuit we know that if we

Digitized by Google

could succeed in opening or closing such a circuit at the instant when the current is passing through its zero value practically we would get no arc or, except for causing a cessation or establishing the current, we would not introduce electrical disturbances in the circuit. It is of course practically impossible to make and break circuits at exactly the instant when the current value is zero, and as a result if we close or open a switch in an alternating current circuit containing resistance, self-induction, capacity or mutual induction, which may be made the equivalent in self-induction, we produce disturbances or oscillations in such a circuit over which we have practically no control as compared with the fundamental sine wave of current and electromotive force.

For the most part we have neglected this constant of integration because we have assumed that the disturbance or oscillations introduced in such a circuit very soon disappear. This, however, is not the fact where self-induction and capacity both are contained within such a circuit.

Even with self-induction and resistance only, or capacity and resistance only, theoretically the resultant current from such oscillations will never become zero. Practically, however, the resultant current in such circuits very soon becomes zero.

Referring to Mr. Campbell's paper, equation No. 1, and the last term of that equation, which is $C\,\epsilon^{ipt}$, it may be said that this term is of the nature of the constant of integration to which reference has been made above, but in order that we may adopt symbols to correspond with those used in the paper it should be remembered that C and p are constants either real or complex and that e is the Naperian base and i is the imaginary symbol corresponding to j as used by Steinmetz.

The term p is a constant, either real or complex, and represents the condition of the circuit or network as regards self-induction, capacity and mutual induction, and the other letters of the equation represent quantities as above explained.

Let us now turn to a few paragraphs of Mr. Campbell's paper in order to ascertain in a general way his method of treatment of the subject, the mathematical character of "cisoidal oscillations" and his extremely valuable and specific results and conclusions regarding such oscillations in circuits of the character of existing telephone distribution systems.

In the first place, the paper is not only mathematical but it is more than that; it is metaphysical in its treatment. The author has clearly pointed the way to the treatment of these peculiar oscillations and indicated a method whereby we may thoroughly understand the action, although we may not have control over the establishment, of such oscillations.

In a way his treatment of the subject is analogous to the mathematical treatment of alternating currents many years ago, in which it was shown that the laws of direct currents would not hold for the newly developed alternating currents. In this paper

Digitized by Google

we have the mathematical treatment of these peculiar oscillations, which is a distinct addition to the mathematical treatment of alternating currents in somewhat the same manner as the mathematical treatment of alternating currents was a distinct step in advance of the equations which were satisfactory for direct currents.

To understand the character of these oscillations we need only consider a portion of the first paragraph of the paper, in which it is stated that these oscillations are sustained logarithmically, damped, or aperiodic, depending upon whether the time coefficient p, which really indicates the character of the circuit, is real, complex or purely imaginary. Further, the author has used the term "cisoidal oscillations" in order to emphasize the distinctive character of such oscillations and at the same time to indicate the close relation between such oscillations and the more generally known sinusoidal oscillations.

It is apparent, especially in telephone circuits, that while primarily we have to deal with oscillations which may be assumed equivalent to sinusoidal oscillations, yet in such circuits containing resistance, inductance and capacity it is quite as necessary to understand the laws governing this new kind of oscillation to which the author has given the name "cisoid."

We may get a somewhat clearer idea of these oscillations, as the author states that they are uniquely simple, because the ratio of the instantaneous electromotive force to the instantaneous current is not a function of the time.

Further we are told that the solution for cisoidal oscillations in any finite network may be written down directly without solving differential equations or the use of integration or differentiation.

The author brings out the fact that the use of vectors in the solution of complex quantities in alternating current theory is unfortunate and logically incorrect, and that the tendency of such use of vector quantities in ordinary alternating current theory tends to divert attention from the algebraic theory of complex quantities, which are of the greatest practical assistance in the mathematical treatment of cisoidal oscillations.

The mathematical treatment of the subject by Mr. Campbell in general is to use the mathematical process known as determinants, in order to obtain what he calls the discriminant A of a network, and in Table I, is to be found effective impedances or equivalent networks with two accessible circuits in terms of each other, and of the determinant A. As showing that these peculiar oscillations may be indefinitely sustained and that therefore they must be given consideration in telephone circuits, we find a statement to the effect that the activity of the external sources of power which produce *steady* cisoidal oscillations in any invariable network or one the constants of which remain invariable may assume a stationary value providing such value is consistent with the conditions necessary for current continuity and the conservation of energy.

Digitized by Google

The author has indicated in a most satisfactory manner the mathematical treatment for the conditions existing in an infinite number of circuits which correspond to our well-known eddy currents and to the skin effect, or the unequal distribution of current throughout a cylindrical conductor, which as we know involves conditions regarding which we must make allowances for certain quantities of current for frequencies above those nominally used.

In conclusion, and referring to the summary given in the paper, the author interprets his results from the mathematical standpoint, which concisely are:

1. The complex exponential function or mathematical expression of cisoidal oscillations is a mathematical term of fundamental importance in its own right and enjoys algebraic power or energy relations quite as important as those of real functions.
2. The correlation between sinusoidal and cisoidal oscillations may be reduced to a few simple rules covering power, currents and electromotive force.
3. The distribution of currents in any network of conductors having constant values is that of stationary dissipation of power.
4. The distribution of cisoidal currents in such a network is reduced to the equivalent condition of stationary driving point impedance or admittance.
5. The cisoidal power may be and is employed as a most convenient means for investigating the division of instantaneous power between resistances and reactances of a circuit or network.
6. Determinants may be used for the general solution of cisoidal oscillations in any invariable network or network having constant values, and the author has shown how the different impedances of such a network may be found directly and has also indicated how concealed circuits, mutual impedances or self-impedances may be eliminated. Also the author has given applications covering free oscillations and infinite systems of circuits.

In conclusion it should be said that not only is this paper of Mr. Campbell's fascinating from the standpoint of the application of mathematics to physical problems, but he has indicated a method of accurately determining the conditions existing in telephone circuits in which there are oscillations due to self-induction and capacity over which in practice we have practically no control, and if you can imagine conditions in a circuit in which the ratio of instantaneous electromotive force to instantaneous current is not a function of time we can to a small degree appreciate into what depths Mr. Campbell has extended his investigations leading to the solution of what are unquestionably some of the most important problems to be met in the transmission of telephonic currents in extensive telephone transmission systems.

Digitized by Google

DISCUSSION ON "NEW AUTOMATIC TELEPHONE EQUIPMENT," AND "THE SEMI-AUTOMATIC METHOD OF HANDLING TELEPHONE TRAFFIC," LOS ANGELES, CAL., APRIL 26, 1911.

(Subject to final revision for the Transactions.)

J. W. Gilkyson: Being responsible for the revenue produced by the manual system of this town, I hardly think it is incumbent upon me to discuss, or at least in any way to malign the competitor of the automatic. It has many phases which meet the requirements of the community. I hope, though, that in the future the semi-automatic will be the neutral factor in bringing together both the manual and the automatic. and I cannot help but think that will be the final result. The fundamental thing is economy—economy in central office operation, economy in central office equipment costs, the elimination of sub-exchanges, and the facilitation of the trunking appliances.

Mr. Keller: Regarding the automatic and manual service, I will quote from a letter I received from Europe from a friend of mine, who went to Berlin, Germany, to promote and build an automatic system. There are a few passages that are exceedingly interesting. Before going to Germany, he came to Los Angeles to see what we had, he returned by way of San Francisco. There he says, he changed his mind somewhat on one phase of the automatic feature, namely, the secondary line switch. In our automatic system here, each subscriber has one individual line switch, and we use secondary line switches to a very limited extent—not at all in connection with the subscriber's line. But in San Francisco, each subscriber has one individual line switch, and before the individual line switch reaches a first selector switch, it passes through a secondary line switch which reduces the number of first selectors to a minimum.

Mr. Luberg has always been opposed to this, but he says since looking into it very carefully in San Francisco, he has changed his mind and he finds the secondary line switch is working very satisfactorily. If he is right, I am inclined to believe it will do a great deal towards simplifying the apparatus in general use.

He says further that at Hamburg he saw in operation there a 40,000-line central exchange under one roof and it is now being enlarged to 80,000 lines. He states that it is a manual distributing system, which means that the call comes in at an A board where one A operator is provided for 800 subscribers. This operator has nothing to do but to extend the call to a B operator who answers the call. The B operator again extends the call to a C operator in the wanted 10,000 group. C has the multiple. After extending the call the B operator is cut out of the connection. The service is supposed to be fine. Referring to the cable service he mentions here that it is frightful. He says the average cable length for a subscriber is three and one-half miles.

Further on in his letter he asks what our average is. I have not quite arrived at my figures yet, but in our Olive Street exchange we find it is about a mile.

Digitized by Google

"Just now," he writes "we are installing a half-automatic exchange in Amsterdam. By the term 'half automatic' we mean a system similar to the Clement Automanual, *i.e.*, the subscribers station is the usual C. B. manual apparatus. When the subscriber calls he gets a connection first with an operator who sets up the connection with a push button keyboard. After the impulse machine has run down, the operator cuts off again. The switches are absolutely identical with the regular automatic outfit."

He says that the engineers of the German government, for as you all know, the postal authorities handle the telephone situation throughout Germany, deliberately put in this half automatic system with the intention of putting in a full automatic later on. He says the only reason that they do not make this change now is because of the cost of the calling device which is estimated at about five dollars more than the ordinary telephone instrument. Otherwise, they would make the entire installation automatic at present. Whenever they want to change their apparatus to automatic they can do so.

That looks to me like a very sensible method. If they must have a full automatic they can do so without any extra expense in the installation—that is without any waste.

It seems that the government engineers have decided that measured service should be furnished where a manual exchange is in use, and a flat rate with automatic. They take the stand that it does not cost materially more for a man to have many calls over an automatic phone than it does for a limited number of calls, while with a manual board the expense of operating increases in proportion to the number of calls, which we all know to be a fact.

"A Dr. Steidle, in Munchen, has designed what he calls 'automatic group systems.' About twenty to forty subscribers with very few calls per day (metered service) say about two to three calls per day, are connected to a relay switching station located in the basement or attic of the house, or placed in the near neighborhood. The relay combination gives access to one of the two exchange lines. In the exchange the calls are handled manually at present. Calls to the group line are distributed by 40 point connectors, also placed in the relay groups. He figures for a 20,000-line plant about 6000 heavy talkers with individual lines, and 1000 relay groups with an average of 14 lines attached to each. He therefore would provide 1000 relay groups with 1000 batteries. Now, don't smile at that, they actually put in about 60 of such groups, in and around Munchen.

"So you see we Germans just at present have the two telephonic extremes—an 80,000 line single exchange and a thousand fold subdivided plant seriously proposed by a very fine telephone engineer."

I should not wonder if we may have a similar situation to face sooner or later. Personally, I cannot say anything about half

Digitized by Google

automatic, for several reasons. In the first place, I don't know much about it, but it seems to me that if the half automatic is used as a step forward toward a full automatic, that it is the proper step to take, but it also looks to me that if one cannot change it to a full automatic it is a step only half forward. It is just like changing from a horse car to a cable car—a sort of step between. Now, if that step between is a step toward making it a full automatic, I think it is a step in the right direction. I think that the full automatic will soon be the only factor in the field.

K. B. Miller: The idea suggested by Mr. Keller of using the semi-automatic as a stepping stone to the full automatic is one way of looking at it. The probabilities are that the one controlling factor in the matter, a factor which is likely to be more and more a controlling influence, is the atittude of the public. The fact is that the telephone companies are serving the public and it is the public that must be pleased. Now, my experience so far, has shown me that either the automatic, where the subscriber spells out his own connection with his finger, or the manual, where the subscriber merely asks for what he wants, is capable of giving good service, and either of them is capable of satisfying the public.

It is often argued that the automatic's success in pleasing the public is transitory—akin to the liking of a child for a new toy. I have studied that phase very carefully and, while I know that some of you will disagree, I can only arrive at the conclusion that, at present, the public will be satisfied with either way of doing it, provided good service results, and we all know that good service may result from either method. The atittude of the people may eventually swing one way or the other or it may split and result in two permanently disagreeing factions. There seems to be nothing impractical in the idea of the combinationof the two schemes, giving automatic instruments to those subscribers who want them, and connecting these directly with automatic switches; and giving to those subscribers who want to feel an operator at the other end of the line, no automatic transmitting devices, but merely ordinary telephone instruments, practically along the lines of Mr. Clement's system. The same automatic switchboard would make all the connections and disconnections, these being controlled directly by the subscribers in the one case and by the operators in the other.

A. H. Griswold: I was very much interested in Mr. Winston's last paragraph, which is one of the strongest in his paper.

"The man who attempts to prophecy what the future equipment will be, is putting himself up very much as a prophet."

In comparison with many of the other sciences, we have had rapid changes of type of telephonic equipment, and certainly we will have in the future a great many more changes before we approach the ideal.

In the final analysis, the primary thing that we must strive for is service that is reliable and efficient, and therefore service

Digitized by Google

that the public desires. It may not be possible to combine in one system a type of service that will meet the desires of all of the people. There may be room for two classes of service, just as there is for the electric car and the steam car, one may offer advantages that the other does not. The thing, therefore, that must be studied is what the public wants. It may not be determined by engineers particularly, any more than to establish these various systems and try them out. It may not necessarily mean the most beautiful piece of mechanism, or the most rapid service, but it will mean the most reliable and most efficient service.

Most of us in using the telephone, if the service be reasonably reliable and the speed of answer be reasonably fast, do not worry very much about the time interval.

The proper equipment in the future may be manual, full automatic, the so-called semi-automatic, semi-manual, automatic distributing system, or some other type, but what ever it is we must have the first considerations fulfilled, that it must give reliable and efficient service, and service that the public desires. Having these first requirements, the secondary consideration, and one which I sometimes think we let precede the first, is the question of providing the best type of equipment at the least ultimate cost, meaning not only initial cost but resultant and subsequent charges.

It might be interesting to know if Mr. Winston in his automatic distributing system has made any provision for reverting calls. That is, when one subscriber calls another subscriber on the same line.

K. B. Miller: In connection with the reverting call proposition, I agree that we ought to hear from both these gentlmen about it. The reverting call is a pretty mean thing to handle with the manual system, as we all know. It seemed at first wholly impossible for an automatic system to take care of it, and yet automatic systems have been made to do this in an even more direct way than the manual.

A. H. Babcock: The automatic and the semi-automatic telephone systems appeal to me from the standpoint of the man who pulls the switch at the subscriber's end. In other words my mind at present is concerned entirely with the subscriber and not with the engineer who is constructing these things. I have a feeling after seeing the inside of one purely automatic telephone system, and having had it very fully explained by the engineer who installed it, that if there is a failure on my part to receive connection with the number that I want, it is due to my failure in handling the apparatus, rather than to the failure of the apparatus itself. Consequently, when I am asked to use a telephone system wherein I give an operator the number that I want, and she does then that which I would do, which is, I understand, the semi-automatic system, it is merely introducing another link and a very weak link into that chain.

Digitized by Google

I call a number in San Francisco very frequently. Five, six or seven repetitions of that number have been made repeatedly, and they are spoken distinctly into the telephone, too. I can't see from the subscriber's standpoint what there is to be gained by putting that extra link into the chain. I prefer a piece of mechanism handled by myself, rather than the intervention of an operator who may be tired, may not be well, may be thinking of other things—the human element, entering in all the time between what I want and what I get. In other words, the nearer we get in all our public service work, to a piece of apparatus directed by one person, the nearer we will come to getting satisfaction. Now, remember, I am speaking merely from the subscriber's and not from the engineer's point of view.

Ralph W. Pope: I wish to call attention to one of the features of the manual system, which is the only system used in New York City, that does not appear to have been considered in these discussions. I refer to the distinction between the individual subscriber working direct with the central exchange, and the subscriber working through a private branch exchange. I understand that in New York City the growth of the private branch exchanges has been very large, and where the service is sufficient to warrant it, is always preferred. I have had both experiences. Formerly, until four years ago, we worked direct with the central exchange. For the last four years, we have worked through a private branch exchange. The service through the private branch exchange is far more satisfactory, for the reason that the operator is more in sympathy with the business, pays more attention to the calls, and is apparently not overworked. That is to say in our particular exchange there always appears to be a little margin of leisure, so that the number can be repeated back, and the operator will not get away from the instrument before the subscriber has an opportunity to correct the number if wrong. When the number is repeated back direct from the exchange, half the time I can't understand what it is, and if I do and it is wrong, the operator is gone before I can make the correction. That is not true of the private branch exchange. This leads me to corroborate Mr. Gregory's statement that what we want is not so much rapidity of service, as reliability of service. There is loss of time, no doubt, in handling a call through a private branch exchange, but then there is also a gain in comfort. In working with the central exchange, we are expected to keep the telephone to the ear until the final connection is made. With the private exchange, the number is given and the telephone hung up and when the connection is made the operator rings up and we go ahead with the work. In other words, we don't have to wait with the telephone at the ear while the connection is being made. That is to me a very satisfactory arrangement, through the elimination of being obliged to sit and wait for what may be a quarter of a minute or half a minute or a minute, with the telephone at the

Digitized by Google

ear. I may say right here that while I do not use the central office connection regularly, sometimes when I am in other parts of the city where I have to call up the central office and do this waiting, it is especially annoying. This all tends to bring in another feature in the telephone service, and that is the comfort of the subscriber. Mr. Babcock admits that he gets irritated. Subscribers wish to eliminate all the trouble possible, and one of the principal virtues of the common battery system is that it has eliminated the necessity of turning the crank. We simply go through the motion of taking up the telephone and putting it to the ear, and then if you simply hang it up and wait until your bell rings, you know that you have your connection.

J. W. Gilkyson: I wonder if a comparison has ever been drawn by Mr. Babcock with reference to the number of mishaps that he might have with the automatic in placing a call himself. He does not charge that error up to himself. He simply hangs up and tries it over again. He may do it two or three times, while he immediately becomes provoked at the manual operator that mistakes his number.

With reference to the private branch exchange, that is a question that we have had considerable difficulty in handling. In many instances, operators are employed by the parties served with the private branch exchange service; many of the young ladies receive a box of candy, etc., from certain individuals of the corporation and get excellent service from the company. On the other hand, the man that is abrupt, gets poor service. I believe if the standard of the private branch exchange could be adopted by the company that there would be a more uniform service. I don't think Mr. Pope's would be better or worse. That is a condition that exists. He speaks about placing his call with the operator. She performs that function that ordinarily a man on a direct connecting line would have to withstand. If that line is busy at the time he calls, he is told the line is busy. The operator has performed that function, and he has to wait. Where would the private branch exchange differ if he gets the report that it is busy? If the private exchange gets a report that it is busy, she makes a note and calls it at another time, and the connection is put up, and the man who is busy, figures it out as an excellent service, but he does not perform the function himself. It is the duty of the girl that operates the private branch exchange, which, of course, could not be expected in service given to the public, and could not be taken into consideration.

A. H. Babcock: I yield to no man in my respect the telephone operator as a woman earning her own living. I find no fault with the operators, because I know of some of the conditions under which they work. I have a great respect for their astounding skill by which they handle an immense number of calls per hour. But I do find serious fault with the con-

Digitized by Google

dition that produces the situation I have just outlined. My conversations referred to are with a private exchange operator who is on our own payroll. I hear her struggling with the central office to get that number straight, and when I say that the number called for has been twisted out of shape six or seven times, it is by skilled operators whose business it is to handle those calls—not between me and the operator, because our private exchange operator knows perfectly well what number I want. It is not my grief, except as I have to wait, but it is hers. It seems to me the farther we can get away from that kind of thing, the better. I don't think it is fair for Mr. Pope to compare his present easy time, pushing off his job of making a telephone call onto his paid operator, with the troubles a subscriber has who cannot afford, by reason of his small service, to hire and pay a private exchange operator. The condition to be met is to give good service to the greatest number—not to a few of us who have private exchanges, or who can send boxes of candy to the operator. Possibly if the telephone expert who has just made the suggestion that a box of candy would improve the service, had realized the implication contained in that suggestion he would have expressed his thought differently. A Public Service that requires lubrication by means of boxes of candy needs some intelligent reconstruction.

F. C. Newell Jr.: Mr. Babcock has just stated that the public is really the supreme court in this case. In cities like Chicago and New York, where there is a great foreign population, the numerals are a sort of universal language. When the operator cannot understand the foreign tongue, it seems to me the numerals are to be preferred. I would like to have somebody state the advantages and disadvantages of the foreign population.

K. B. Miller: In France, I am informed by some of the foremost French telephone engineers, they consider that very point as one of the strongest arguments for the automatic. It seems that the French language, with which I am not familiar, does not lend itself as readily to the spelling out of the digits of a number as our language does, and that as a result there are a great many more misconnections, and a great slowing down of the service. That appears particularly in the trunk operations where an A operator passes a connection on to a B operator. The difference between the number of calls that a B operator can handle in France with the same type of equipment, and that which we handle in this country in manual exchanges, is remarkable, and I have heard it attributed mainly to that fact that the French language does not lend itself so readily to the transmission of numerals. Undoubtedly other factors enter also.

A. H. Babcock: How about the Chinese exchanges? Is there anybody from San Francisco who can give the experience with them?

Mr. Keller: The Chinese in this city have a private exchange of their own, or, rather a small exchange with a Chinese operator,

Digitized by Google

who speaks English and establishes the connection for the Chinese. They have not yet adopted the automatic in this city. In San Francisco, however, they have adopted the automatic system, the automatic calling device with Chinese numerals on it instead of the numerals we use, and operating exceedingly successfully. In fact, it has been more generally accepted by the Chinese in San Francisco than by the general public so far.

There is another feature that I have just been told of by a young man that came from Havana. In Hanava there are a great many languages spoken, and the automatic there has become very popular on account of the fact that all of the various nationalities can secure their parties without having to converse with any operator or any other person except the party they are calling.

Ralph Bennett: I am very much interested in the four-party line. We have one at our residence from the old company, and I have discovered that I hear not only our own but all the neighbors calls from both sides of the line.

Very frequently they ring on our line, one bell, and after ringing awhile we answer. "Central wants the party whose ring is two bells," When told so she says. "Oh, I didn't know that. They didn't tell me that." It seems to me that this difficulty can be readily corrected on an automatic where the subscriber rings the correct call automatically.

K. B. Miller: It is a simple matter to have selective ringing on party lines in manual systems. Several successful schemes are available.

W. D. Moore: We maintain in our system what we call an observation desk. It means that the service we give is constantly under observation. This observation desk indicates the moment the calling subscriber takes the receiver down; the moment the operator plugs in to answer; the moment she rings; the moment the called for subscriber takes the receiver down to answer; the moment he hangs up; the moment the disconnection is made. This action is automatic—we do have a little automatic—and different colored lamps indicate the different movements and it is recorded as the action takes place. Now in each exchange there are so many observations taken each day. That is the way we determine the standard of service that we are furnishing. It also indicates the efficiency of our operating force. We figure that any operator—that is, the answering operator—can handle, during the busy hour of the day, the peak of the load, approximately 265 calls. That is, she can finish 265 calls. Now if we find there is a falldown in the service in any particular exchange, by referring to the peg count, which is taken on the tenth day of each month, we note that the operator has become loaded down and a redistribution of lines is made throughout the entire number of operators and the result is, of course, a natural improvement of service. We also have certain methods by which we procure increased efficiency from the operating

Digitized by Google

force. Of course this is all worked out upon what our experience has shown us that one operator can handle without an excessive strain.

Our figures showed for this city—the last time I heard them quoted, which was some six months ago—that there was one-tenth of one per cent of the entire number of completed connections that were rung in error and this is a very small fraction of the total number of calls.

That is taken from the observation service. We can tell at any period of the day, any hour, just what class of service we are giving in a particular exchange, in a particular town or territory; and the figures have shown that one-tenth of one per cent of all the calls completed were rung in error. So, as to that part of the manual system, some particular fault of the automatic can also be found to offset it.

It appears to me, taking the subject as a whole that it is as Mr. Griswold said when he referred to the last paragraph of Mr. Winston's paper that he sums up the entire proposition in a few words. He said that it is probable that before many years the differences of opinion which now exist as to the relative advantages of manual and automatic will disappear, and that definite standards will be adopted for the various conditions of practice. There is no question about that. I believe all telephone engineers agree that we can predict that without fear of being contradicted.

Mr. Clement described his semi-automatic system, but as I have not read his paper through, I could not grasp the full details, but I believe, just speaking for myself personally, that this is the eventual outcome. I might also refer to a remark of Mr. Keller He said that the semi-automatic would be, or could be used as a stepping stone to the full automatic and that if that could be done, it would be very desirable. I believe that what he was thinking of was the saving that could be made by deferring the expenditure necessary for substation equipment to some future period. It is my opinion that is not what is going to happen in the future. I think that the automatic will be the stepping stone to the semi-automatic for this reason—you know that recently there have been certain laws enacted which prohibit the employment of female labor for more than eight hours out of any twenty-four. This places a burden on the smaller towns and exchanges. In a large city where there are some very busy people, such as railroads and other large offices, using the telephone constantly, the amount of work that the subscriber must do to secure his connection is an important factor, whereas in a smaller town it need not be given consideration, as there are no large business houses using the telephone at a very rapid rate. Therefore it appears to me that the automatic will ultimately be used for furnishing service in smaller towns, say up to a capacity of 1,000 lines, as the part the subscriber may play in procuring his own service is not very important. In the

Digitized by Google

larger cities where a man has his mind occupied with various details, he is not so anxious to manipulate the instrument himself. As a result, it appears that ultimately the desirable service, or the service the public is going to demand, would be the manual.

In handling the manual service, our present switchboards are designed so that we can place within the reach of one operator 9,600 lines. Of course, on a jack per line basis, this would mean an additional number of stations probably a ratio of 70 lines to each 100 stations, but when you reach the capacity of 9,600 lines, it means additional multiples. It means that you will have to install trunk switchboards that will have additional multiples and are considered second units. The capacity of each unit will be 9,600 lines. That is, an operator answering a call on the first unit must out-trunk same to the second unit.

Now in a city like New York, where they have over 300,000 telephones, it resolves itself to a question of what per cent of the total calls are out-trunked, and it is figured that when approximately 70 or 75 per cent of the calls are out-trunked, it is just as economical to out-trunk 100 per cent, which means all calls originating at the 'A' position will be out-trunked.

Mr. Clement describes a clearing-house system and also operating centers, but I could not quite grasp his idea. It would seem to me that the ultimate solution of this problem would be something like this—to provide a number of operating centers in a city like New York, each located at what we term 'Wire Centers', that is a particular center at which the greatest number of wires radiating from same would be the shortest, when you take down your receiver, your signal would show before the 'A' operator and after giving your call—say for instance Broadway 4519—she would then simply manipulate the keyboard and the rest of the action would be automatic, that is, it would select a trunk, arrive at the other office, select the particular number you wished to talk to and ring same—then you would have solved the operating problem and also the telephone problem as well as it can be solved in our day and time. I am of the firm opinion that the ultimate solution of the problem of handling telephone traffic in the larger cities is the semi-automatic method and that the full automatic will serve the smaller cities.

Mr. Schuler: There is one thing that the gentleman spoke of that interests all of us who are in the telephone business. We are in the telephone business for one thing, and that is to sell service. Now, the point in my mind is this, that the company that is in the telephone business and is going to do the most business is the one that sells the best service. I have in mind a place where the Bell Company had nine hundred subscribers and the Independent started with 250 subscribers four years ago. Now the Independent company has 1,567 sub-

Digitized by Google

scribers and the Bell Company has less than 200. The one thing that accomplished it was service.

Now, what constitutes service. Service is constituted by a man going to his telephone and getting the number he wants in the quickest possible time and getting the best possible transmission after he gets his number. That is telephone service. If you go to your telephone and try and try to get a number and don't get it, and even after you do get your number you don't get transmission, you are not getting what you pay for, and the man in the telephone business is not delivering what he is paid for doing. In my mind the best proposition for delivering telephone service, I don't care whether it is wireless or with wires, or whether with telephone or without telephone, that will put A in communication with B and give A that communication in the least possible time and give them both the best possible transmission.

I have made a number of tests—I happened to be manager of the first two-wire system put in existence—I made a particular investigation of why we could not get business. The Bell people were not giving service. We were giving service so far as our calling and our transmission were concerned, but we were not giving service because the people did not use the apparatus right. Now, if we had had in that little Illinois town the automatic, or semi-automatic service, I believe we would have gotten the business. I called on 100 of our subscribers and asked each one which they thought best, which they preferred to use, and they preferred to use the manual service, but they admitted they could get better service over our lines, but they did not want to be bothered with the necessary trouble.

I have made a number of other tests in regard to service. I tried getting 100 subscribers on the manual and getting 100 subscribers on the automatic service. The automatic service was a new plant and everything was working right, and I would get my 100 subscribers in a great deal less time, making allowance for the parties who did not answer, the moments lost in waiting for parties who did not answer on one was as much as the other —I would get my automatic subscribers in less than 80 per cent of the time it took on the manual. I visited 100 subscribers and asked them which they preferred to use—whether they preferred to give the operator the number and let the operator call it, or the automatic. A large per cent preferred to give the number to the operator, so I am thoroughly convinced that the semi-automatic is the best equipment.

H. B. Tupper: Mr. Clement in his paper says, " It appears that after the operator has answered the calling subscriber and puts up his connection, she clears out and if the subscriber does not get the called party he has no means of determining whether that subscriber does not answer or whether that line is in trouble, unless he should flash his hook and probably come in on the apparatus again and go through the same sequence as the first time"

Digitized by Google

We use a method in the manual system, we have toll switching positions, automatic stick down keys, which work the same as those Mr. Clement speaks of. The operator plugs in to the subscriber's calling jack and the ringing is done automatically through a machine ringing segment on the ringing machine. This machine ringing device throws out alternating currents and direct currents at intervals on the operator's line to the subscriber, and it will continue to ring until the subscriber removes his telephone from the hook, which indicates he does not get it and he can get her again and tell her conclusively whether the line is in trouble or whether the subscriber does not answer. That is a point that should be embodied in the automatic—the possibility of the subscriber getting in touch with the operator without going through the sequence of working up his automatic machinery again.

C. L. Cory: I have enjoyed the discussion of the automatic, the manually operated and what has here been called by different names, the half or semi-automatic or automanual telephone systems. Considering the matter somewhat carefully from yesterday, it would seem that we should view the telephone situation fairly and from two entirely different standpoints, one with the attitude of the subscriber or customer, the other as necessarily viewed by telephone engineers who have been engaged for years in perfecting all of the very complex apparatus adopted and so successfully used in telephone systems.

The requirements of the subscriber may be compared to that of the customer requiring illumination, using electric light. Illumination from such a source of light is needed as a substitute during certain hours of each 24-hour day in place of the natural and free illumination available in day time. As long as the sun provides sufficient light the individual only finds it necessary to raise the shade to the window in his room. In the absence of sunlight many years ago man found it necessary to devise a substitute, and perhaps in the order of use, pitch pine, the candle, and the coal oil lamp, all of which sources of light were under the complete control of the individual desiring the service.

Upon the introduction of gas and incandescent lamps the service was not completely under the control of the customer. In somewhat the same way we may consider telephone service.

I myself frankly believe that the method by which one calls or attempts to get in communication with the person with whom a conversation is desired should be considered from the psychological as well as from the engineering standpoint, although of course the methods that may be employed by the customer and devised by the telephone engineer are engineering problems, but it will not do to lose sight of the attitude of mind of the subscriber in coming to a definite conclusion as to the best system which may be employed.

Those requiring the use of electric light had nothing to do with the change from the carbon to the tungsten incandescent

Digitized by Google

lamp. Yet the service is much better and cheaper with the latter than with the former. Viewed exclusively from the standpoint of the customer, he might have been thoroughly satisfied for all time with the old carbon lamp, but nevertheless the customer is pleased and gratified as a result of the introduction of the tungsten lamp as a substitute for what was previously considered entirely satisfactory, namely, the carbon filament lamp. The illustration may be crude, but it may serve as evidence that the character of service planned for the customer by the inventor may not be the most desirable to the individual paying for the service.

Again suppose it is my desire to speak to Mr. Miller. As we are now both in this room I merely address him. The entire conversation is within our control; barring some noise or similar interference from the outside our mutual understanding of one another can not be prevented. Mr. Miller hears me addressing him and replies directly. Nobody can interrupt our conversation. In a way such a conversation may be likened to sunlight as a source of illumination. It is free. It is controlled as we choose and no interference is possible from others.

When artificial illuminants were introduced without question the idea was in so far as possible to get results approximating the illumination of the sunlight, not free of course, as this would be impossible. Similarly I can not talk with Mr. Miller when he is in Pasadena as I do here, nor can I talk with him when in San Francisco. We need some artificial arrangement, which is the telephone, in order to make our conversation possible at the greater distance. Notwithstanding this, my attitude of mind as I desire to talk with Mr. Miller when he is distant certainly approximates the condition which we can so readily establish here when we are within a few feet of one another. This obvious fact will certainly be admitted by all. It is the work of the telephone engineer to approximate that condition.

To put it in a little different way, Mr. Miller may be across the street, or in Pasadena, or Long Beach or Redondo or San Francisco, and I desire to talk with him. No matter where he may be it is my desire if possible to carry on a conversation with him as I may do here in this room. This is the attitude of every telephone subscriber. In order, however, to get into communication with Mr. Miller, what is my preference. Spell out his location myself, because that is what it amounts to in the automatic system, or remembering that I am subject to error, would I prefer to take the telephone off the hook, addressing an operator in the central office and trust to the system, which includes operators and devices, to connect me with him, no matter where he may be. I have been impressed greatly and much admire the mechanisms that have been evolved in the automatic system, but the question finally comes down to this: would I prefer to simply express my desire to talk with Mr. Miller by giving his

Digitized by Google

number to the central, or individually spell out Mr. Miller's location myself so that I may talk with him.

The preference of the subscriber in such an instance, it seems to me, depends entirely upon conditions. It may be necessary and really demanded that the automatic system be used, by which every individual, no matter what language he may speak, finds it possible to spell out the location of the person to whom he desires to talk, as was stated here might happen in Havana, or any other city containing in its population subscribers speaking many different languages who use the telephone, but it does not necessarily follow that this is desirable in a city using say 300,000 telephones and covering an area less than the city of Los Angeles.

Naturally the telephone engineer has confronting him the problem of providing as far as possible a system so that I may talk to Mr. Miller if he is in Los Angeles, only across the street, or in San Bernardino or San Francisco in a manner as nearly as may be as we talk together in this room. As a matter of fact, I may not know in the beginning where Mr. Miller is, and it does seem that the plan where we have combined local and long distance service, whereby a skilled operator is used in locating the person to whom one desires to talk, may perhaps be much better than to have such locating done by the customer, who can not possibly be so skilled as a regular operator.

If the automanual as has been described in one of the papers here will make it possible for the subscriber to call up central, give the number desired, and then the operator in the central office by using a similar automatic device can the more accurately, speedily and economically connect the subscriber with the individual called, that system it would seem would be the best of the three under discussion as treated in the papers presented.

In conclusion it should be said, I think, that the problem of devising the best possible telephone system should be viewed not solely from the standpoint of the subscriber, but very largely so. At the same time, all of the possibilities should be given the most careful consideration by the telephone engineer. The requirements of the subscriber should be met as far as possible by the telephone engineer, whether the service required is long distance or local, in a small community with a comparatively small number of telephones, or in a great city of large area with hundreds of thousands of telephones, any two of which may be connected together in the least possible time, and in the operation of which, without question, there will be a decided peak load during certain hours of the working day which must be taken care of if the service provided is satisfactory.

Arthur Bessey Smith: The paper presented by Mr. Clement is very interesting in that it presents clearly a very essential question involved in exchange operation. The question may be stated thus. Is the human element necessary and desirable

Digitized by Google

in connecting exchange lines? While every human activity requires human attention to some degree, there are many things which, on account of their nature, may be better and more satisfactorily handled by machinery. Before we can decide whether or not the telephone exchange comes within the automatic field, it is necessary to consider two features, *viz.*, the nature of telephone service and the practicability of selecting lines by automatic machinery. Since Mr. Clement has himself acknowledged the latter point, we may confine our attention to the former.

Telephone service consists essentially in establishing means whereby conversation may be held between two points. This is usually limited to speech transmission by electrical apparatus connected by wires. When we have turned such an arrangement over to two or more people to use, we have rendered telephone service. Since the outfit is usually owned and maintained by a company for public use, a fee is charged whenever it is loaned to any person or institutions. Also because the people must pay for telephone service it demands that the service shall have some degree of quality.

The elements of quality in telephone service are, in order of importance, as follows:

Accuracy of connection, quality of transmission, speed of connection and disconnection, proper treatment and ease of securing connection.

Voice transmission is usually very good in modern exchanges so that for our present discussion we may omit it from the list. This leaves the following:

1. Accuracy of connection.
2. Speed of connection and disconnection.
3. Proper treatment.
4. Ease of securing connection.

Theoretically, it might seem that the human element is indispensable to the rendition of good service, but practical experience has shown that almost all of an operator's work is inherently mechanical, requiring no judgment. In the total of a day's work, the calls which require intellect are so few that they can be cared for by very few clerks.

The automatic switchboard can render excellent service in all of the elements named above. These I will discuss in detail.

The transmission of a number by mechanical and electrical means is far more accurate than by voice. In the messenger company analogy, used by Mr. Clement, the public would not entrust its business to such a concern if address of a parcel were given to the messenger orally .Nothing but a plainly written address will do. There are many chances of mistake in oral transmission, both on the part of subscriber and of operator. The act of spelling out a number with a calling device is naturally conducive to accuracy since it is done through sight and touch, the two senses upon which man places his greatest reliance.

Digitized by Google

From the standpoint of the subscriber, automatic service is quicker than either manual or auto-manual. The time from the initiation of a call to its connection through the apparatus is from a third to a half as long with automatic as with auto-manual. The saving when compared with manual service is even greater.

It may seem strange to compare a human operator and a switch as to " treatment of the public," but the relation exists and is very real. Far from being " the principal ground for confidence " the operator touches the public with a treatment as variable as her moods. The automatic switch treats the public with uniform courtesy—the courtesy of implicit obedience. In all but a limited number of cases no subscriber asks more than that his desire for a connection shall be quickly and accurately made, which service the switch certainly performed. The automatic switch accords the public the best possible treatment.

Generally speaking, to relieve the subscriber of all work possible is not necessarily inconsistent with the highest type of service. The highest and best service is rendered when we most completely meet the subscriber's desires and needs. Further, not all the labor of making a manual call is felt by the hand, for the brain and the organs of speech are involved. Compared with the oral transmission of a number, it is a relief to turn the dial. The subscriber does not feel it to be a burden, but regards it as an efficient means to an end. He asks for *results*.

To sum it up, I believe that the amount of telephone traffic which requires direct access to human intelligence is so small as to be negligible. The small class of calls which requires special attention should be handled as at present by clerks, who are not operators. For the great bulk of traffic the human operator is not only unnecessary, but a positive hindrance to good service. People desire *service*, that is, telephonic connection, which the automatic switch has the special capacity to give. The perfect rendition of this service has established among automatic users a feeling of strong confidence.

Henry P. Clausen: Mr. Clement states that in the manual switchboard an operator can attend to from 280 to 290 connections per hour. While I do not think that this figure is any too high, the records of the average exchanges throughout the country will run more closely to the 250 calls per hour figure, and that only during the busy ten hours of the day. During the peak hour, however, operators will frequently go as high as 400 calls per hour, and for short periods an observation has shown that an operator can answer as many as 425 calls per hour. 300 to 330 calls during the peak load is not at all unusual. In fact, in one of the exchanges mentioned by Mr. Clement the writer has found a record showing 288 calls per operator's hour, and it is interesting to observe that 63 operators on duty at the same time were averaging this number of calls.

According to Mr. Clement's statement, only 31 per cent of

Digitized by Google

the total cord circuits are in use at one time during the peak load. The writer does not think that this can be absolutely correct, and, in fact, upon consulting the records of one of the exchanges cited, 63 positions were in service, each equipped with 15 cord circuits, and out of a total of 18,200 calls during the peak load, allowing three minutes per conversation, 96 per cent of the connective means were in service; and, taking the run of calls during this particular day, out of a total of 189,000 possible three-minute conversational connections, 135,000 calls were taken care of, which then gives us about 70 per cent of the connective means in service during a continuous run of ten hours.

Another statement made by Mr. Clement refers to the expense of operating the trunk circuits in a certain exchange, which, he says, amounted to 31 per cent of the total operating charge. As Mr. Clement gave the name of the exchange, the writer was in position to examine into the records and found the following: Out of a total of 21,300 calls, requiring 198 operators' hours for handling them, 6500 were trunked outward, which equalled about 30 per cent. The incoming trunks amounted to something over 5600 calls during the day, and these were taken care of by 58 B operators' hours. Mr. Clement probably had the above records before him when preparing his statement, and therefore did not carefully consider the local conditions, for, when it is learned that in this particular exchange the B operators, instead of answering calls of from 350 to 400 per hour, as is the usual practice, were only answering 98 calls per hour, it will reveal to every traffic man a serious condition of affairs, requiring correction.

In discussing full automatic exchange operation, Mr. Clement suggests that irresponsible persons may call anyone and cause a great deal of annoyance without danger of detection, and, as I understand the description of the automanual system, the same difficulty remains, for, when an automanual operator sets up a connection and presses the starting button, this connection passes beyond her control and she is not able to detect any improper use of the telephone.

I believe that it is admitted that in the full automatic exchange one attendant is required for every 700 subscribers, these attendants taking care of the automatic switches, supervising them while the exchange is in operation; but it is not brought out by Mr. Clement that the automanual system, employing, as I understand it, the same number of line switches and trunking switches as the full automatic, must also employ the same number of attendants. This would very seriously increase the operating expenses.

As to the statement that one day's training is sufficient for an automanual operator, this may require some qualification in the direction of understanding how efficient such an operator may be for performing the difficult feat of handling subscribers calling for service.

Digitized by Google

It is further stated that all operations in the automanual system are standard. How are the different classes of service taken care of; for example, pay-station, measured service and flat rate service. Such calls as require the recording of subscribers' numbers should prove very difficult in the automanual system, for the operator has nothing before her to indicate the calling subscriber's identity, and it would appear difficult to obtain it other than by inquiry, and then at the risk of being given the wrong line number or wrong information. At any rate, pay-station and measured service calls, which in many exchanges run into quite a large percentage of the total number of subscribers' calls, cannot be handled at the high rate claimed in Mr. Clement's system.

In the comparative work units submitted, and based upon the number of movements of the A operator in handling a local call, a more equitable division could have been made, but Mr. Clement makes the serious error of completely ignoring the presence in the manual switchboard of overlapping operations upon the part of an operator. Each distinct operation is said to be performed to the exclusion of any other; this, while it is true for the automanual system, is not the experience in manual operation, for in the manual switchboard an operator can respond and does act upon audible and visual signals practically simultaneously, and at the same time each hand may be used for a different operation. As a matter of fact, it would be impossible for an operator of a manual switchboard to handle 300 connections per hour were the overlapping not present, for telephone calls do not always accommodatingly originate in equally timed periods as they should if each operation were distinct and separate from every other operation, for at times three, four, or more calls appear upon a position at practically the same instant and a great many of the answering operations are then performed practically simultaneously.

It is at this point that I want to bring out one of Mr. Clement's suggestions, "When a subscriber calls, if he receives a quick response, he is satisfied, even though a slight delay occurs later," for it is the overlapping operations which permit the operator of the manual switchboard to produce what we call a three-second's service. An operator cannot possibly complete, say, four calls in their entirety in three seconds' time, but she can answer the calls in that time by quickly inserting the answering plug into the jack and calling for number.

In the automanual system, as understood by me, an operator is expected to answer 1,000 calls per hour, which in an exchange originating 5,000 calls during a busy hour means five operators. What is the result when—as it is entirely probably—20 subscribers' calls are received within a given second or several seconds' time. According to the figures upon which the automanual operation is based, it takes an average of 3.6 seconds for an operator to respond to and set up an automanual connection;

Digitized by Google

therefore, in order to answer the 20 calls, it will require 72 seconds time; dividing this by the five operators who are not able to perform any overlapping operations, it appears that at least 14 seconds must elapse before the last one of the 20 calling subscribers is disposed of; and with more than 20 calls the delay would be much greater. This, I believe, is one of the most important points not discussed by Mr. Clement.

C. S. Winston: Mr. Griswold brought up the question of the method of handling reverting calls in an automatic system. Most of you probably know that a reverting call is a call from one station on a party line for a second station upon that same line. In manual equipment this does not present any very difficult problems, but in the automatic it is a very different thing. In the three-wire automatic the problem has been solved and it is possible for one party to call for another on the same line without knowing that he is calling for a station upon the line upon which his station is located. In the two-wire automatic, using automatic ringing the problem is entirely different. Up to the present time, I believe, no satisfactory means has been found for accomplishing this result, and hence it is necessary for a subscriber to know that the telephone of the man with whom he wishes to talk is upon his own line. If he does not, he will call and receive a busy test just the same as if he were calling for a separate line which was in use. The number of calls, however, of this sort, I understand, is not very great, and I do not think that any particular trouble has been experienced with that difficulty.

No telephone system is or ever will be absolutely without defects, or entirely ideal. This refers to manual equipment as well as automatic equipment. In the automatic system, if a subscriber upon a party line takes off his receiver at the time the second subscriber upon that same line is signalling, trouble is sure to be met as the impulses which are sent subsequent to the removal of the second receiver will be lost and the proper station will not be called and possibly no station will be signalled. I see no way in which this defect can be overcome. It is one of the defects which seemingly are inherent in automatic equipment.

In automatic equipment difficulty is met in the handling of measured service. This is true either when service meters are used at the central office, or nickel boxes at the subscribers' stations. That is, if a party is called and another party responds the charge is made just the same as when the call is properly completed.

Mr. Griswold also brought out another point in regard to two subscribers plugging into jacks of the same line simultaneously in the system which I referred to as the automatic distributing system. I don't think that trouble will be met with on this account. In the system which my company has laid out, more or less in detail, there is a relay in the cord or trunk circuit which

Digitized by Google

operates as soon as the plug is inserted into the jack of a line and if two plugs are inserted into two jacks of a line simultaneously, it would be necessary for them to operate at the same instant before trouble could result. I don't think the chances for this to happen would be as great as the chances in the manual system of missing the busy test and plugging into the jacks of a line already in use.

It was suggested by Mr. Miller, I believe, that a possible solution of the problem might be in the combination of the semi-automatic and the full automatic. It hardly seems to me that this would be a satisfactory arrangement. In communities where the plan has been used of operating both common battery and magneto telephones the results obtained, I understand, are very unsatisfactory. If a man has one type of telephone and a friend of his one of the other type, he is apt to make up his mind that he prefers the telephone which John Jones has and he is not satisfied until he gets it. It seems to me that trouble would be met with if this suggestion of Mr. Miller's were followed.

Such an arrangement would complicate the central office equipment, require extra apparatus equipment and hence the expense of maintenance would be increased. I don't think the service would be as satisfactory as if either one of the two systems were used alone.

It has occurred to me that there may be confusion due to the fact that in my paper I referred to the " semi-automatic system " and Mr. Clement referred to a system, practically the same, as the " automanual system." There are no differences as far as operation goes and the differences which exist are all merely differences of detail. The automanual, or semi-automatic, is nothing more nor less than an automatic system in which the dials are removed from the subscribers' stations and operators at the central office do the work which is done by the subscribers in a full automatic system.

Very frequently in semi-automatic, or automanual there is more or less trouble due to the fact that after the connection has been established, as Mr. Clement has already stated, the operator is entirely disconnected from the circuit. If for any reason the subscriber desires, after the connection has been established, to call the attention of the operator, or perhaps I should say to converse with the operator, the operation of the switch-hook will disconnect the apparatus entirely and instead of calling the attention of the operator he called originally, he may get some other operator. This may cause trouble, although I understand not a great amount has been experienced in the three or four places in which the automanual is now in use.

It does not seem to me that automatic equipment is likely to be used in small towns. I don't think there is likely to be any great conflict of opinion in regard to this point. In small plants the cost of maintenance must necessarily be low and the original cost of automatic equipment, and the cost of maintenance, would in all probability make it prohibitive.

Digitized by Google

Mr. Clement stated in his paper that in a telephone system subscribers pay for service and hence should not be bothered with duties which should really be done by the operator. I hardly agree with him in this respect. I seems to me that if the subscribers do not object to performing this work, and advantage is gained by using full automatic, it is certainly justifiable to do so.

This brings us up to another point. One or two of those who took part in the discussion have stated that they thought this whole subject would result in the adoption of the system which would give the best service. While, of course, service will play an important part, yet I think it is a secondary consideration. The foundation of any business is laid upon the returns which are expected from the investment; that is, you get down to the old proposition of the almighty dollar. If it is found that automatic equipment can be bought and operated at less expense, and hence will give greater returns on the investment than manual, it is the system which will be used.

In places in which automatic has been employed, the subscribers have shown that they are willing to operate the dials without complaint and it seems to me that the operating companies must decide which system will meet their ends best, and install that equipment universally. The service, of course, will be improved, and kept at as high an efficiency as possible; but it all boils down to the fact that it will not be improved unless an improvement will increase the returns upon the investment.

E. E. Clement: The work which I present is individual work, and I have tried to present it in an individual way. I have tried to look at both sides of this subject impartially, and having gone into the question very thoroughly on both sides, I long ago personally decided in my own mind that the semi-automatic principle, in whatever form embodied, would necessarily be used in the future. Of course I have advocated that ever since. Now, a man ought to be able to give some reasons for the faith that is in him, and that is what I have tried to do in my paper, and shall continue in these remarks.

Mr. Keller read a very interesting letter from a friend of his in the Siemens and Halske Company in Berlin, in regard to their work over there. I would not refer to this except that Mr. Keller in discussing it stated that he had been surprised to learn that the Germans had been developing along my line. Dr. Raps and Mr. Grabe, of the Siemens and Halske Company, have been in touch with me. They were over here several years ago with a party, and were given every opportunity to see my work. They are desirous of introducing these improvements in Germany, and I mention this so that no false impressions will arise as to the situation. I do not believe that the Germans or any other foreigners have done any substantial work in developing the automatic or semi-automatic systems in any form in which they appear in this country.

Digitized by Google

Mr. Keller also referred to changing what he called "half-automatic" to full automatic, and to "mixed" systems. I tried to make clear yesterday and in my paper that in my automanual system there is one vitally distinctive feature, (among a great many original features) which is not found in any full automatic system, or in any of the ordinary so-called "semi-automatic" systems, of the type referred to by Mr. Winston. I refer to the use of an operator's trunk, separate and distinct from the talking trunks which are used to connect the subscribers for conversation. Disregarding this, the basic principle of semi-automatic amounts to no more than moving your senders in from the subscribers' stations to the central office. There is no reason, either technical or psychological, why a mixed system should not be employed if it is wanted; that is, we can arrange our circuits so that all the connections are made by automatic switches, but some of the subscribers can have senders and work the switches direct, while the rest of the subscribers are handled by the operators. This condition would actually exist during the process of changing over an existing full automatic equipment to automanual, which we can do very readily, but for permanent use I would not care to recommend such a system.

In considering my individual operator's trunk, it must be remembered that any semi-automatic system which ties the operator to the talking trunks necessarily loses almost all the advantages of operator-centralization. The key to the solution of this problem is in the provision of separate operators' trunks, which are automatically connected to and disconnected from the talking trunks, and which can be made of any length desired, so that the operators can be centralized or shifted around, or divided into different centers, or otherwise handled as traffic conditions and the discipline of the operating companies may render desirable. This, with a number of other features, are broadly new and peculiar to my automanual system. I know quite a number of these features have been taken up and followed by others as we have developed and announced them. I am aware that other people will try to get into this line of business, but these are commercial questions with which the Institute is not concerned, and I am sorry that others have brought them up. At the same time, I am glad of this opportunity for an answer on my part. I may say that I believe, commercial and legal questions being disregarded, if every telephone manufacturing company started making similar apparatus, the supply would not exceed the demand in the next ten or fifteen years.

In this same connection, the matter of making a recall has several times been referred to. It is stated that if the calling subscriber gets his connection and the operator is cut off, the subscriber cannot call her back. This is true, and no trouble can or does flow from it, the facts being quite contrary to Mr. Winston's statement this morning. In my system the subscriber hangs up his receiver, is instantly cleared out, takes down

Digitized by Google

his receiver and instantly gets an operator, who may be the same or another. The whole operation of hanging up and taking down is practically instantaneous, much quicker in fact than any ordinary recall could be. What is the use of tying the operator up and interferring with the work. If a man wants to make a recall, he can do it better by making a fresh call. If he wants to report some trouble, or to make another call, he can get the operator or he can get the trouble clerk, without delay.

Reference has been made in the discussion to the full automatic system operated through subscribers' metallic lines without grounds. As I have stated, I can operate my central office mechanism from the subscribers' stations, over metallic circuits, and in fact I may state broadly that I can do with this system anything that is done or could be done with any full automatic, for the obvious reason that I have the full automatic equipment at the central office; and I can also do anything with this system that can or should be done in a manual system, for the obvious reason that I have operators at the central office, while the subscribers' equipments and line connections are the same as in the manual system. In fact, when I started, a good many years ago, to attack these problems, I first of all worked out those which are common to all automatic practice, among them the metallic circuit problem, which seemed very difficult in the beginning. Years ago I was able to make a report with blue prints of two wire metallic circuits which had been then successfully working automatic switches for a long time, using timing solenoids instead of the magnets referred to by Mr. Winston. In that full automatic circuit I also had selective automatic ringing, which has been successfully working ever since, having been grafted into the automanual circuits. I believe the principles thus discovered are indispensable for good practice.

Mr. Griswold, and some of the other speakers, on the question of reliability, have referred to the question from the subscribers' standpoint alone. I think we must look at this problem from every standpoint, not only the subscriber's but the company's, and also as Professor Cory has said, the standpoint of those engineers and their associates who have given their lives to developing these systems. In the practical aspect of the question, there are only the subscriber, who wants service, and the company, which is called on to furnish that service in enormous quantities, and must therefore practice economy as a matter of absolute necessity. Economy however, must be effected without detriment to the service given the subscriber.

I have devoted a good deal of time, in conjunction with Mr. Boylan, to collecting and comparing traffic statistics. If you will read the first ten and the last ten pages of my paper, which are devoted largely to discussion and tabulation of this traffic data, it will save me from going into a lengthy explanation now. In regard to some of my diagrams, particularly Figs. 17 and 19, you will observe that I have shown only two curves for

Digitized by Google

comparison, one the manual curve showing cost of operating, and the other my automanual curve. I did not attempt to plot a curve showing similar costs in a full automatic system, because of a desire to be extremely impartial, preferring to present the figures, as I have in the argument, and leave the comparison to you. My reason for this was primarily that in the full automatic system, you cannot entirely segregate the operating expense from the maintenance and other costs. Now, how the various operating companies employing full automatic systems, keep their accounts, I do not know in detail. I have seen some of their reports and some of the data used in making up their statements, and they are very interesting; but I would not plot a curve without compiling and comparing these to an extent that has not been within my power in the time allowed for preparation of this paper. However, I believe, and I think you will agree with me after reading the figures I have given, that if the automatic cost curve were plotted in Figs. 17 and 19, it would lie between the manual and the automanual curves which I have plotted. I have stated in the paper that the net saving per annum in mere operating expense as such, by the use of full automatic equipment, cannot be more than 50 per cent of the manual operating expense in a system of any size, and that it is probably very much less. This may or may not agree with the facts in all cases. That is for you people to determine. You have better statistics at your disposal than I have. I show a saving however by the automanual over the manual in one given case of 77 per cent (see Fig. 17), and I also show an extreme case which I may state is based on studies in the city of Cleveland, Ohio, of the traffic of both companies which are competing there, in which the use of the automanual system will save 86 per cent of the present manual operating expense. As opposed to this, if the two companies were to trunk direct between their switchboard by manual methods, it would increase their present separate operating expenses by an average of 40 per cent, which makes a total difference in my favor, operating under the same conditions, of 120 per cent of the present total operating expense. The question for you automatic men to determine is, what will you be able to do with your equipment when you meet a similar condition.

Traffic conditions in the telephone business at present are fairly comparable with those in the railroad business. This country has been growing with most tremendous leaps and bounds, and we have not yet reached anywhere near the limit. When you have only a few instruments to handle, it is easy to consider only reliability, and forget the cost of service. But when you are dealing with a city exchange handling from six hundred thousand up to several million calls per day, and those calls cost anywhere from $1.50 up, per thousand (the Cleveland combined figure is $1.96) then it becomes indeed a serious question, and you cannot yield to the subscriber entirely. With

Digitized by Google

the automanual handling these calls at 25 cents per thousand, however, the subscriber should get all the attention he needs. This system is designed to give the subscriber the same grade of service that he gets in the best manual system, that is the individual attention of the operator, and the benefit of her training with all the other benefits flowing therefrom, but at a minimum cost to the company.

One question asked is was what happens if a line is called and the subscriber does not answer, the operator being then off the connection. For this condition I provide a special tone test signal, which comes on if desired after a certain number of rings, or we can handle it through a monitor, or in any other manner possible in the automatic. I preferably provide signals for every condition, which I find the subscribers learn to distinguish very readily. At Ashtabula, we have a busy-back, substantially the same in its functions as that with which you are familiar in your automatic systems. We also have a don't answer signal, but the calling subscriber preferably hears the ringing. We also have a special tone test for the case where the calling subscriber hangs up before the operator gets to him, which she hears when she listens in. We also have an indicating board, with lamp banks, and other signals, so that any condition of trouble or line in trouble can be traced by the wire chief. We also have the other expedients for various purposes with which you gentlemen are all familiar in your practice. Our circuits are very full and complete as to details, and a great many of these are novel, but time forbids my going into them.

With respect to reverting calls, I have no trouble with those. The condition which must be produced when you go to test your own line, which ordinarily would then test busy, is almost obvious. You must produce a neutral condition at the instant of your own test. This has been done in several ways, and we have done it in practice by having the last impulse from the sending machine which works the test relay, also sent back at the same instant to the calling end to reverse the test potential. This applies to a two-wire circuit as well as a three-wire. We test on the tip side usually, and have no trouble at all. I am surprised that Mr. Winston made the statement he did on this point, but presume his information was defective.

I agree with Mr. Winston that the percentage of reverting calls is so small that it hardly pays to take care of it. I took this up with a number of the managers of the larger companies in the east, to see what experience they had; and while there are special test signals available for reverting calls, as you may know, in the old manual practice, these people didn't consider the number of such calls sufficient to make any regular provision for them. The way we take care of them at Ashtabula Harbor is this: There is a master switch at the back of a key set, so the operator getting a call for another party on the same line, can cut on a special first selector and disable the associated

Digitized by Google

secondary selector, so that no other calls can come in on her key set for the time. She then handles that call in the ordinary way. The caller gets his party and then the selector switch is knocked down, leaving only the connector on the line. All it needs is ringing and a battery supply. The battery supply, through one bridge connection in the connector, only, is a little less than normal where you get feed both ways, but, on the other hand, you don't need quite as much, because you are talking through a short circuit. In order to ring past the calling party, you have to tell him to hang up.

You will observe from the tables I give in my paper, that this does not affect the operator's efficiency. The percentage of such calls is very small, although we have quite a party line development in Ashtabula.

Mr. Foster referred to complaints against the operator. I tried at first to eliminate all sounds and all disturbance from the calling circuit after the operator had gotten the number, that is, to prevent the calling subscriber from hearing any of the actuating impulses or ringing, or anything else. We found, however, that silence was a bad feature. A man gets the operator, he gives her the number, and he has no means after that, if there is dead silence, of knowing whether she is doing anything or attending to the line, and if, through mischance, he does not get his connection, there is complaint. We have now arranged our circuits so that a subscriber, after the operator gets the number and starts the impulses, hears those impulses faintly, and he can also hear the ringing. He also knows that the operator is not on the circuit after she has made the connection, and that the ringing is automatic, so that if there is any blame, he attaches it to the other fellow for not answering.

Now, with regard to the condition of strained nerves on the part of the operator, and that sort of thing, in the paper I have taken occasion to show that in this keyboard arrangement by confining the operators simply to asking the number, we relieve them of a very large part of the purely manual strain; that is, we take the actual work to be performed off them and put it on the machines. The work on our keyboards is very light. The touch is more delicate than the touch of a typewriter or adding machine. We have made it as light as is consistent with reliable operation. So we don't have a condition of strain on the operators, and no one operator is any busier than another. Their work is very light, and if there is any complaint coming or any discourtesy or anything of that sort, the operator does not bother with it for one second—she simply pushes two keys, this puts the party on to the trouble clerk, or some one else, and she is through with it. Our operators are confined to just one thing—asking numbers and setting them up; and to that extent they are mechanical; but they have brains, and if there is an incoherent number given or any trouble, their brains get busy. They don't get any complaints and they don't need them.

Digitized by Google

The question was asked what happens if a cable goes bad or some other condition arises that might affect a whole group of the apparatus. We have special provision for that the same as in the manual or the automatic. We have the same resources so that we can switch off a whole group of lines and put them on to the wire chief or in the hospital or somewhere else, if desired.

In regard to favoritism on the part of the operators, the P. B. X. operators being accessible by means of candy and so on, if not properly fixed giving poor service—there is another feature in the automanual system which I consider of some importance; that is, that the operator does not know who is calling. Reference was made in the discussion of one of the papers to the primary and secondary distribution in Mr. Keith's system; that is, the automatic electric. I have a primary and secondary distribution apart from that of the operators, by which practically any trunk in a very large group can be reached, and it can be arranged so that any subscriber may reach any operator in the whole exchange. That makes it practically impossible for any operator to know who is calling, unless she has a very remarkable memory and the transmitters are very uniform, or the man tells her, and then she is running the risk of the supervisors reporting her. That eliminates the question of favoritism entirely.

With regard to foreign subscribers, it happens that we have had some experience with them. We have quite a foreign population at Ashtabula Harbor, and I don't think we have had one complaint from those people as to the operators not understanding their numbers. This may result from the fact that some of the operators in the exchange—not all of them—were drawn from the native population. I presume they are accustomed to the linguistic idiosyncrasies of the people. In the case of Swedes, select a Swedish operator for them, the same as you have Chinese operators in San Francisco. Before spending forty or fifty thousand dollars extra for apparatus to accommodate these subscribers, better invest in a little foreign assistance.

Another question raised relates to possible defective ringing in case the calling subscriber does not give the number of his party on the line wanted. It is possible to group the lines so that all party lines are segregated; and then if a calling subscriber fails to give the letter or number, the operator can ask him. She repeats the number back as she sets up the keys, and the subscriber would then probably repeat the ringing letter even if she did not ask. Where all the lines in an exchange are party lines, the question would always be asked.

As to the methods of compiling our data: I have a photograph of the Horograph, so-called, made for automobile timing. It is a very interesting machine, and I will be glad to show it after the meeting. It is guaranteed to be accurate to one one-hundredth of a second. All our reports have been based on

Digitized by Google

this and on automatic peg counts. We have an arrangement of the relays so our peg count is taken every day and all the time, and is absolutely accurate. All the calls are recorded, together with the manner and efficiency with which they are handled.

Mr. Babcock stated that introducing the operator was introducing a weak link. I think that point has been answered by some one else, but I am not going to let it pass, because it is, I think, an error. The answer is this: If, as Mr. Babcock stated, and as we know to be the fact in manual systems as well as automatic, a considerable percentage of the troubles reported is due to the subscribers calling, then where can the weak link come in from introducing a skilled and trained and habitually poised operator in the place of the subscriber? I have covered that subject pretty fairly in the paper, and I don't think I will go any further into it, because I have not the time.

As regards the private branch exchange, practically every line is a private branch line. If you subdivide your system they all get the same service, and they all get personal attention, and at the same time you can have if you want private branch exchange operators. I do not think it is as economical or as good practice to divide the group of operators if it can be avoided. Nevertheless, special conditions will sometimes arise. I know in New York we figured on some parts of the city, for instance, in the brokerage district, where the men are too busy to stop for anything. They want to make a string of calls each day at a certain time, and an operator who can give attention to that is absolutely essential. There it pays to put in automatic branch exchanges. One operator handling these exchanges ought to do the work of about three the way they go now, even with the varied calls that would be made on her.

Finally, as to measured service: I can provide special operators, and segregate measured service lines and other different classes of traffic so as to bring them in to these operators; but I prefer not to, sticking always to the basic principle of confining the subscriber's operator to asking the number and setting it up. We only need to loop any class of trunks through a monitor's desk and the monitor then takes care of the special condition. A special operator who can take those things off a regular A operator is an economy, because not doing anything else she becomes very expert at this irregular duty—almost as expert as the A operator herself. In other words, you have an organization of specialists instead of one person trying to do a dozen things. Of course pay-station calls are handled in the same way.

We have also a system of metering specially applicable to this connective system. I refer to the Telechronometer. This is not the time or place for me to go fully into that, but I will state very briefly that in line with my theories on handling the traffic I also have some very definite theories on the subject of measuring that traffic. I do not believe, and I never have believed that the counting of calls, whether they were charged

Digitized by Google

up as answered or not answered, is fair, either to the subscriber or the company. I do not believe, and I do not suppose any of you who are in the operating end will disagree with me, that a flat rate service is any more fair to the company than it was in the days when the lighting companies used to give so many lights for so much a month. If a man chose to burn them 24 hours a day, of course the company was out. In some cases a flat rate promotes increased use of the telephone and an increase in the number of subscribers, but this is a temporary resort only. The Chesapeake & Potomac Company in Washington, for a time followed a policy of inviting people to use the residence phones frequently, and even to ask the neighbors in to use them. Of course the purpose was obvious, and I think it has been satisfactorily fulfilled. But I prefer to measure the service; and I think we do it satisfactorily. It is measured in units called telecrons. A telecron is a unit of time-distance, and I firmly believe that is the logical way to measure telephone service—plus a base charge which should cover the cost of that much of the operator's time and depreciation on the apparatus, and so on, which is chargeable to the mere answering of the call if the called subscriber does not reply. With an apparatus of this kind, the effect is that at the end of the month the meter shows the total service which has been given during the month in telecron units. If a man has talked three minutes over a circuit one mile long, he has three units charged against him—I am speaking roughly. If he has talked ten minutes over a circuit five miles long, he has fifty units against him, and the toll service and everything else can be metered so as to show the total service. We have an instrument which will give the number of calls also if you want to know that. The distance-rate is adjusted by the operator, who may be the subscriber's operator or a special operator, at the time the connection is made, so as to correspond with the character and length of the circuits employed. The time element is controlled by an apparatus which is running all the time at the central office.

Mr. Clausen appears to be the only one who questions the figures given in my paper. These figures were prepared, and all of my generalizations were drawn, with the utmost care. The following explanations, numbered to correspond with marked paragraphs in the Clausen communication, will substantiate this statement.

1. Mr. Clausen lost sight of the fact that the 280 to 290 hourly connections were specified by me as busy hour non-trunked calls. He makes the statement that the average exchange throughout the country shows a record of 250 calls for the ten busy hours of the day. A general statement of this kind without reference to the variation in percentage of outgoing trunked calls is unsafe to say the least. It may be well to mention that while an operator can handle 290 non-trunked calls, she can only handle 200 calls where the percentage of trunking is ninety.

Digitized by Google

Mr. Clausen remarks also that operators frequently handle 400 and in some cases as high as 425 calls per hour at the peak of the load. As Mr. Clausen does not specify we must assume that they are non-trunked calls. Neither Mr. Boylan nor I have ever seen or heard of an " A " manual operator handling anywhere near this load. It requires no traffic experience for one to pass on this statement as being beyond bounds. Even were we to assume that the subscribers were not required to give a prefix or affix with numbers on all calls, the number of hourly calls mentioned would still be excessive.

The average calls per operator busy hour in the exchange referred to by Mr. Clausen is 262 and not 288 as stated. The number of calls during the busy hour is one eleventh of the total daily calls. Mr. Clausen evidently estimated a lower figure than this.

2. This statement is incorrect in four particulars. First, the busy-hour load is not 18,200 calls but 16 500 calls; second, the 16,500 calls do not represent completed connections but from this figure must be deducted the " busy " calls, calls for the time, etc., which, conservatively, amount to 12 per cent of the busy-hour calls; third, the average conversational connection is not three minute in this case, and inquiry fails to show such an average in any exchange in the country having 7,000 lines or over). The average subscribers conversation in the exchange in question is 98 seconds; fourth and finally, the average length of conversation during the busy-hour is 25 per cent less than the average for 24 hours due to a greater part of the conversation being of a business nature.

The claim we make is that not more than $33\frac{1}{3}$ per cent of the cords on a switchboard are in simultaneous use during the peak of the load. The exchange referred to has 63 positions with 15 pairs of cords per position, making a total of 945 pair of cords, $33\frac{1}{3}$ per cent of which would be 315 pair of cords.

There are 16,500 calls handled during the busy hour. It has been stated that 12 per cent of these calls represented busy calls, etc., but to be conservative we will cut this figure to 7 per cent leaving a total of 15,345 possible completed connections.

The average cord time is 98 seconds, less 25 per cent during busy hour or 73.5 seconds, which figure represents 49 connections per cord pair per busy hour, multiplied by 315 pairs of cords ($33\frac{1}{3}$ per cent of total) equals 15,435 calls, or 90 *more connections than are actually handled during* the busy hour.

3. Mr. Clausen raises the point that only 98 calls per " B " operator-hour were handled in the west office of The Kansas City Home Telephone Company, instead of from 350 to 400 per hour which he states is the usual practice. Mr. Clausen is confusing the calls per " B " operator hours with the call per " B " busy hour.

There are several factors, however, which preclude the handling of 350 to 400 calls per " B " busy hour in an office such as that

Digitized by Google

in question, the leading factor being the absence of apparatus at the " B " position which should enable the operator to handle such a number of calls. It is true the " B " operator could handle 350 calls if given the " manual selective ringing service;" 400 per busy hour with " machine ringing," and 500 per hour by utilizing " keyless trunks."

Another factor which determines the number of calls the " B " operator can handle is the number of offices connected with her order wire circuit. With the particular type of apparatus in use at the exchange in question the operator could handle 350 calls provided only one office were connected to her call circuit. This figure would be reduced to 300 calls when a second office was added, 260 when a third office was added, etc. Thus the point that only 98 calls per operator hour is answered shows a condition not unusual and which will be found in any branch exchange connected by order wire to several other exchanges.

4. In compiling the comparative work units we allowed for overlapping operations on the part of the manual operator and the illustration given by Mr. Clausen in which he assumes that 20 calls would land on 5 automanual positions at the same instant can be applied to the manual service. We admit that under a condition of this kind which however, is very far from common, the last subscriber of the 20 would naturally have to wait a little longer than the others. This however is true of any system.

Digitized by Google

DISCUSSION ON "ELECTRICITY IN THE LUMBER INDUSTRY." LOS ANGELES, CAL., APRIL 27, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

R. L. Noggle: I might say just one word in favor of electrically operated sawmills, and that is this: You will find that in using electricity, in place of steam you will save on your insurance. Where I am in the northern part of Idaho, we have started to furnish power to two different mills which consume some 750 h.p. The only talking point we could impress them with at all was that of insurance. We are running our plant entirely on refuse and shavings from the saw mills and in turn sell those people 600 h.p.

J. A. Lighthipe: I think the advantage in the lumber industry, if electrically operated, is not so much in operating the sawmill as it is in supplying power to the logging camp. For years they have been trying to get hold of a large portable saw that would take care of the logs. I would like to ask how they have succeeded. They saw up a tree seven or eight or nine feet in diameter, and the question of operating those saws is quite a question. We made a failure at Folsom, not so much in operating the mill as in the lack of logs to saw. At that place we had a great dispute over the amount of power necessary to saw. The boss sawyer used to take a log and jam it through as fast as he could. He would crowd the mill to the utmost. That is about the last experience I have had with any large logging concern. Inquiries have come from the neighborhood of Seattle to know if anything had been developed for an electric saw out in the lumber camps, away out where they drop the logs and section them up. That is where it is needed more than anywhere else.

C. Pemschel: In the first part of this paper in which the author describes the installation at the Elk River & Potlatch Lumber Company, he informs us the hand mills vary in horsepower from 30 to 275 h.p.

I think it would be very interesting for us to know the horse power under the different conditions that the mill is operated. The size of the cut and feed. This same thing also applies to the edges. I also notice that he says that the planers in the planing mills are driven by 75-h.p. motors. Seventy-five horsepower is rather large for the largest size planers and I surmise that one 75-h.p. motor drives a group of planers. Any information that he has, that is, the horse power, that these planers take under actual operating conditions I am sure would be very interesting to the readers of this paper.

The second part of this paper in which electric logging is taken up is interesting to me as I have given this matter considerable consideration and thought and have worked out the scheme of operating these donkeys by means of compressed air and last July read a paper before the Logging Congress

Digitized by Google

in Portland on this subject. A copy of this paper can be seen in the August issue of *The Timberman*.

J. A. Lighthipe: Seventy-five horse power is nearer right than twenty-five.

The tendency in all of the mills is to force the machines. Power is very cheap and time is very costly and they are apt to overcrowd everything. I found that particularly in the great big band saws where the boss sawyer was trying to drive the logs through as fast as he could. The planers did the same way. They fed those machines up to the limit. The work in these camps is not to be compared with any railroad shops you ever saw. The lumber is cheap, power is cheap, and labor is high.

Ralph Bennett: It appears to me that you were using your planer for resizing. Taking off some very heavy cuts to get a different sized material. That need not occur in a lumber yard or at the mill.

I installed about two years ago a rather large planing mill for this district in which we used electric drive throughout, and turbines for generating. That mill has 40 h.p. on each planer, and they handle the material very nicely.

In this same connection I investigated the possibility of using electric power in their saw mills, and installed a 300-kw. turbine in what they speak of as Mill B. They propose to rebuild Mill A, or build a new mill electrically driven. We found that the 250,000 B. M. mill took about 900 h-p. running idle, 1100 on normal load, and possibly 200 more when all three bands happen to catch at once. The amount of power given in this paper for the bands would not be at all applicable to Pacific redwood mills.

The Potlatch method of logging must also differ somewhat from that used in the redwoods, because it is necessary there to handle not only a logging engine but a yarding engine. The logging engine could be reached by a wooden pole line along the railroad. The yarding engine is, however, three thousand to five thousand feet beyond the road engine on a steep hillside, without any permanent surroundings whatever, and it would be necessary to reach it with a cable. These logs are at present sawed by hand where they are felled. Indeed an enormous possibility in labor saving in the woods exists here. Fuel for the road engines represents less investment than fuel to the yard engines. The road engine is reached by an oil tank car, but oil has to be packed to the yard engine. This oil is brought from Southern California, and taken into woods where they are burning their waste to get rid of it.

At the mill it is true that fuel is valueless. It is also true that the cost of preparing and firing wet sawdust is high. There are times when steam cannot be kept up. By feeding more of this material to refuse burners, and less to the boilers, it can be disposed of at much less cost. The economy of high grade turbines is therefore an advantage after all.

Digitized by Google

Most modern engine-driven mills have two engines, one for the front and one for the back of the mill. A breakdown in either engine shuts the mill down. Two turbines of the same capacity, both running, would be but part loaded. A breakdown on either turbine would permit the running of the remaining installation with the uninjured turbine.

The author of the paper speaks of the use of storage battery locomotives in the yard. There are now in operation in California and in the southern states, a great many monorail systems, in which the car travels on an I beam rail elevated 25 or 30 ft. above the yard. When properly installed, this will cover the entire storage area, permitting it all to be used for lumber storage purposes. If lumber is piled in stacks in proper shape and tied together, it can be handled into the pile and stored without any hand shoving whatever, and still in the package taken aboard the vessel or car and so transported as a unit from the sorting table to the wholesale lumber yard, thus reducing the cost of handling and storage to a minimum, at the same time producing under proper conditions a much better grade of lumber with quicker handling.

Digitized by Google

DISCUSSION ON "CONTINUITY OF SERVICE IN TRANSMISSION SYSTEMS." LOS ANGELES, CAL., APRIL 27, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

R. J. C. Wood: The first thing that attracted my attention was that the substation in which the line ended was solidly connected. It might be that interruptions could be made still shorter if each substation could be connected onto either end of the light or power lines, unless of course, the steam plants which the author mentions as being on the other end of the line, are kept in operation at all times, ready to pick up the load.

It is stated that an open short circuit taking place on the line is opened in a few seconds if it does not clear itself. This would seem to allow the possibility of burning the line in two. The more general practice, I believe, among the companies here is to drop the voltage as soon as possible and clear the short circuit.

It would also seem that the method of cutting in on the line every 30 sec. might be very severe on the generators and transformers.

With reference to the number of patrolmen, it states there are eight patrolmen and there are 106 miles of territory covered. That is not counting the lines twice over, for there is a double length of about 164 miles. I would like to ask the author if each man works by himself or both together. If each man works by himself it would mean he only had about 20 miles to look after.

There are several references in the latter portion of the paper in regard to electrolytic lightning arresters, and it would be interesting to know if they have met with universal success.

Reverting to the matter of testing lines to find out which section is in trouble, I would like to know whether the author plugs the line right in on the bus, or whether he separates the generator bus and then tests the thing out easily, bringing it up from a local tension.

I didn't notice any reference to the size of insulators. They look to me like 14-in. insulators.

P. M. Downing: It is very gratifying to have a paper of this kind presented and have someone come forward with data giving the number of interruptions that have occurred on a system of this kind to be honest enough to give the cause of the interruptions.

I note in the data given that but few, if any of the failures, are attributed to poles or crossarms burning as a result of leakage over the insulators. I infer that a majority of these failures are the result of lightning discharges or from high voltage disturbances. Whether or not any part of them could have been prevented by the use of electrolytic lightning arresters is a matter of conjecture. To one having to do with the operation of long high voltage lines this arrester is a very interesting piece

Digitized by Google

of apparatus. On the system with which I am connected we have never installed any of them on the high voltage lines, their use being limited to the low voltage cable systems. Some transmission companies have installed them but from all of the data that is available they seem to be still in the experimental stage. My own personal experience with arresters is somewhat limited. In the central part of California the only type used is the horn type, their installation generally being limited to the generating important switching centers. Lightning itself strikes the lines occasionally but the result is seldom serious. It may strike the line between poles and burn one or more wires entirely off without effecting in any way the insulators, pins or poles adjacent to where it would strike. During the past winter we had two occurrences of this kind where it struck the line and burned off two wires in each instance. In neither case were the insulators damaged and we would probably not have known what caused the trouble had we not found where the lightning had gone to earth through several poles near where the trouble occurred. This would bear out the truth of the theory that disturbances of this kind were local in character and the high voltage would not extend any distance over the line. This being the case, there is a question in my mind as to whether or not any type of arresters unless located at a great many points along the line will entirely eliminate the troubles due to high voltage conditions of this kind which are known to come up occasionally.

I note that comparatively a few automatic switching devices are used but that fuses are substituted at the substations.

A fuse is all right in its proper place. It will work satisfactorily on small transformer installations but for the larger sizes you need something more substantial than a fuse. At one time it was common practice to use fuses on transformer installations up to 3000 kw. but these are being rapidly superseded by automatic oil switches.

There is one piece of apparatus which the manufacturers have not made as great progress in the development of as they have in other lines of apparatus. I refer to the reverse current relay. There are several types of apparatus of this kind on the market but in almost every instance they become inoperative when the voltage drops below a certain point. Where you have a network fed from a number of different points interconnected in a great many different ways you want something that will automatically cut out a line on which there is trouble before the entire network is effected. Having two long parallel lines tied together at both ends trouble might occur on either line which would make it desirable to cut out the defective line at the receiving end leaving load on the good line. If the lines are long and trouble serious the voltage at the receiving end will very often drop so low that the reverse current relays will not operate. The result of this failure to operate is too often a complete

Digitized by Google

momentary shutdown until the switching is done by hand control.

The simplest and perhaps as reliable a reverse current indicator as can be had is the ordinary induction wattmeter. I have used these to fairly good advantage both to determine the location of trouble and also as reverse current relays for cutting out defective lines.

E. F. Scattergood: I agree with the writer of the paper in recommending that generating stations be tied solidly to the transmission lines and that there be no automatic devices employed. As Mr. Wood has suggested, I believe such is the general practice in this section of the country at least. The objection to the automatic devices, so far as they have been developed, except, I believe, in the cases of branch lines, which are in the nature of feeders and represent only a small load, making any reverse current impossible, are greater than the advantages, because when one of these automatic devices goes out it often happens that others follow, thereby causing a great deal more trouble than originally existed and a great deal more delay and lack of continuity of service.

By way of illustration we may form a mind picture of several 30,000 volt feeders with automatic devices leading from a substation containing a bank of transformers connected to a much higher voltage transmission line by means of another automatic breaker. It has happened in such a case that the operation of a feeder breaker caused the higher voltage automatic to open also, thus throwing off considerable load and causing similar breakers to go out elsewhere. It would be much better to run some risk of the transformers than to run the risk of the system as a whole being disturbed in that manner unnecessarily.

Mr. Wood, in his paper, very aptly suggested that probably, as the networks become more complicated, it will be desirable to operate with divisions entirely separated but arranged for paralleling at any time.

G. H. Stockbridge: There are a few things that I would like to call attention to, one in particular being the subject of running the two lines parallel through automatic switches in substations. I would like to ask if any experiments have been made along the line of paralleling at the generating station, say a certain number of transformers on one side and a certain number on the other side, to be separated in case of interruption, thus confining the interruption to one-half the load. We have been considering trying this, but there were some complications raised. I would like to know if it has been tried in this case. I notice the statement, " the details of the system of upkeep employed in connection with the transmission system have been carefully worked out as a great many of the interruptions in service may be avoided by proper maintenance of the lines." This is a broad statement. What would apply in one district would be entirely insufficient in another. For example, we find occasional inspection of the insulators is necessary. Possibly it might

Digitized by Google

require a complete inspection annually of our main transmission lines to insure us from interruption.

I also note that it is provided that when the patrolman working on the line makes his inspection that the lineman makes a solid connection to the ground with a cable. This belongs, of course, to the part of the system where the circuits are on separate lines. With the Edison Company in California, where the two lines are run on the same poles, we find it is essential for the man working on the poles to ground both ends of the circuit.

This table of service interruptions is, as I said before, particularly interesting to the operating engineer, showing as it does the causes of the various interruptions and I am surprised to find the causes are relatively few as compared to what they are in Southern California. In fact, I think in Southern California we have almost everything from balloons to birds on poles, including shepherds who leave their flocks long enough to climb a pole and try to magnetize their knives on a 60,000 volt wire.

The porcelain insulator shown in the paper is familiar to our Southern California engineers as being the old type of insulator used on the 30,000 volt line running from San Antonio Canyon into Los Angeles. When they were first installed we had very little trouble but when the load increased, when we had to use both circuits, there was considerable trouble from pole burning, similar to what Mr. Downing has experienced on his lines. This was eliminated to a large extent by taking a piece of galvanized iron and putting it on the top of the bottom crossarm to provide a conductor between the two arms for the leakage current. We found practically all the fires were caused by leaking across the gap between the top and bottom arm and by providing a channel for this we had but little trouble.

I am interested in the apparatus for taking care of lightning and so forth by air gaps. Our experience with air gaps in this country is not very satisfactory. We found the discharge point varied so much with the condition of the atmosphere. A gap which would be pressure-safe in dry weather would discharge more in foggy weather or a heavy mist. Perhaps there is some way of eliminating this besides installing electrolytic lightning arresters in series with them. If that is so, we would be interested in knowing what it is.

R. W. Van Noorden: Professor Cory gave us a little outline of what was called the psychological side of the telephone business. In other words, he wanted to show that the working of different systems was not altogether dependent upon the inventions and improvements that had been made. There is some question as to whether one system is an improvement over the other or not. In working our power plants, we have a psychological element, it is not like the one Professor Cory spoke about but is more material. I don't suppose there are any two power plants that are exactly alike. There are

Digitized by Google

no two power plants that have exactly the same conditions under which they must operate, and yet there is a great similarity between all plants, let us say, of a certain size. In comparing the working of the Snoqualamie Company and those of California companies, there are many similar problems, but in order to understand these the engineer must understand a great many solutions which he does not learn when buying his machinery, or installing it, or of which the designing engineer may know nothing. I have seen in many cases, where a plant is started for instance and has been running for a year or two, there are changes made, and the engineer will say, "This has cost us more than if we had it in the first place," or "If this thing had been built in such and such a way it would have operated better." Now, the designing engineer did not know that. Possibly he could not have forseen it, but he should have, and as we go along in the science of this work we are learning these things and learning them from the operating end. The point I want to bring out is this, that this paper instead of being simply a description of what a plant has done day by day is really of the utmost importance in helping us to decide what we must provide for in our new developments, and it is just as Mr. Downing said, if the operating engineers would only have nerve enough or be permitted, to come out and give records of this sort, it would do more good to the engineering world than almost anything else that we could get. I am sure I have read this paper with the greatest of pleasure, and while there are many points that come up for discussion among engineers there are points that settle moot questions, questions of theory.

For instance, at one place the author states that if he did not have a Tirrill regulator which held up the voltage he would have had much less trouble in momentary interruptions with synchronous machines. That immediately brings up the subject of the old question between automatic and the non-automatic—I am not referring now to telephone operation, I am referring to power house work. Our experiences on the Pacific Coast have gone to show that the non-automatic workings have been successful where automatic apparatus might not have been, and that is where the question of personality and the psychological study that the engineer has to make comes in. I wish we would have a few more of these papers and that the engineers would consider them of more importance than they do for discussion.

C. O. Poole: There are several features in the system that have brought out points upon which I have debated in my own mind for some time past. One of them is the segregation of multiple circuits by automatic switches. Personally, I have been very much inclined to Mr. Scattergood's views that a good non-automatic was very much better than a poor automatic. Our practice I refer more particularly to southern Nevada—has been to install automatic oil circuit breakers on branch lines

Digitized by Google

and also to protect substation devices. We have found in our experience that a well adjusted, well constructed automatic oil circuit breaker in protecting substations on the high-tension, lines is more reliable than on the low tension. We have found it to work very satisfactorily. I have hesitated however to install automatic switches on the main transmission lines. I can understand, of course, that it may work successfully under Mr. Crawford's conditions. As I remember it, his lines are exceedingly short, and consequently the charge and reaction effects are not so great as on the 200-mile lines. I would like to ask if Mr. Crawford knows of such experience with those lines and if the circuit breakers have dropped out by the line reactions or capacity reactions after the short circuit has occurred. I notice that they use a large rheostat in the tail race for throwing on the circuit before the machine has fallen out of step. I would like to ask if this is one rheostat that is on the bus or a separate rheostat for the separate generators. We had some experience in this line. We installed a new plant and our governors were not put in operation soon enough and we had to control 300,000-kw. by hand, and when a short circuit occurred on the system we had an arrangement made whereby we could throw it over on the rheostat simply to hold the speed of the generator down, and I might add perhaps down to a very low degree, and it worked satisfactorily as long as the wires did not burn out in the tail race.

I note also in Mr. Crawford's paper he states they test the line by, I presume throwing it onto the bus system at the voltage. I would like to ask if he tests it before he closes the line. Also what type of ammeters he uses on the high tension side to indicate the currents.

Ralph Bennett: It has been suggested that we ought to do all switching on the high-tension side. Our system is a 100,000-volt system, delta connected, and we stopped that. We found that every time we switched the load on the high-tension side we got surges that were too great to stand. The insulation breaks down. Some of our transformers are 10,000 kw. and it takes days to get them back into service.

We have installed at each end of our line electrolytic lightning arresters and our voltage rise on loss of load is sufficient to discharge the arresters. We have set the horn gaps back until they are practically non-operative.

We have had in over two years of about 100,000 volts operation so little line trouble that we can say we have had none due to the voltage. We have had a good many bushings broken down and things of that kind but the use of 100,000 volts does not seem so very difficult to us. There is no corona.

Our interruptions are so mixed up with the interruptions of different customers that we hardly know which are ours. Perhaps when we have been operating another year we will be able to say that this, that or the other interruption is due entirely to our own trouble and due to a preventable cause. We cannot say so today.

Digitized by Google

D. D. Morgan: The Pacific Light & Power Corporation has no circuit breakers at the generating stations; everything is tied in solid. We use some of them on the feeder lines and they work very well. They have worked very well in separating the railroad service from the commercial service.

Our experience with electrolytic lightning-arresters has not been very great. We do not believe that they have done much good in regard to lightning. We have had quite a bit of trouble with our insulators breaking down and shattering on our Kern River system. It seems to be very hard to explain why in a great many instances.

W. B. Gump: I will mention a few points relative to the figures previously quoted as to the limiting quantity of power to be feasibly carried over a single transmission line. Considering first the one extreme, a small amount of power, say, 1000 kw., to be delivered at a point 150 miles distant from the generating plant, we find at once that the capital outlay in transmission is almost certain to be prohibitive. In other words: it is evidently far cheaper to install a steam or gas power plant at the point of delivery.

Taking now the other extreme, a 20,000 or a 30,000-kw. load to be delivered the same distance (150 miles), we certainly have to consider continuity of service. Therefore, the dependence which would be placed on one three-phase line under these conditions necessarily involves a large degree of uncertainty.

Stating the proposition in another way: How much can we afford to pay to insure the transmission system against interruption? Or, putting it in still another way: What portion of the total power generated can we afford to have out of commission for a more or less uncertain period of time?

M. T. Crawford: I will endeavor to reply briefly to all the questions. It is true that with our present arrangement we drop half our load at the main substations if one line goes out, but only for a few seconds, as the switchboard operators first act is to switch this load to the live bus without delay. This we have found to be a more positive and reliable way than to employ reverse current relays. These operators display excellent judgment and while their action is deliberate, it is positive. I remember one case several years ago when power went entirely off of one line, and on the other line only one phase was alive. The voltage dip was not severe enough to stall the two 500-kw. rotary converters, and they were kept in running on one phase, by pulling off all the direct current load. By doing this the operator kept current on the polyphase low-tension lines and carried the more important polyphase feeders for about fifteen minutes, with only single phase high tension supply, as the converters were generating for the dead phases. By that time service was again resumed over another line. I don't know of any automatic equipment that can do work like that.

As to multiplying lines—we have tried multiple connections at both ends and at the middle, but experience has been in favor

Digitized by Google

of connection at the ends only, as we have more reliable operators and equipment at these places.

In regard to testing out lines. It is rare that we have to do this directly. If normal service can be maintained with the good line, the chief operator proceeds with some care in locating the trouble. In many cases farmers or others telephone in and report the location of trouble, as the fireworks display is something to remember especially at night. The telephone system is in duplicate on line, on each pole line, and the telephone wires are almost invariably burned in two at the point of trouble. Hence the section showing telephone trouble is nearly always the one having high tension trouble. This section is left open and the rest of the line thrown in, section at a time, at the pole switch, the oil switch at the generating station being set for instantaneous overload release at a light current value. These switches are completely equipped as automatic circuit breakers for this purpose, and the automatic trip kept cut out during normal operation.

The water rheostat referred to is one large unit provided with an oil switch and panel the same as a feeder, and is thrown directly on the bus. Iron wire coils give good results, and I have also made excellent rheostats out of sheet iron. An iron ribbon 2 in. wide by 0.018 in. thick will carry 2000 amperes continuously if supplied with cooling water. It must be in one continuous strip (made by cutting a sheet zig zag) and well supported mechanically.

Our electrolytic lightning arresters have given us fair service on the whole, and we have two makes. They will take line surges from switching and other causes, although when the surge is repeated several times in succession we have had it burn a path right through the trays to ground.

We have only few expulsion type fuses at small stations, and prefer a series trip oil circuit breaker. Our switch experience has been that the additional cost of a more substantial mechanical construction is worth while. We are rebuilding all our pole switches, making them on the same general lines but of very much more substantial mechanical construction.

The failures of insulators were practically confined to the Everett line when it was equipped with 30,000-volt insulators which were not tested before acceptance, and then usually when a high voltage occurred from some other cause. The new insulators were individually tested by our representative at the factory before acceptance, testing each shell for its share and then the assembled insulator at a rain test of 120,000 volts for five minutes. They measure 14 in. in diameter at the large petticoat.

The patrolmen have each a separate section of line, the maximum single patrol being 20 miles. They are stationed at the middle of their territory, and in such a way that available linemen are only 10 miles apart.

Digitized by Google

DISCUSSION ON "THE REFINING OF IRON AND STEEL BY INDUCTION TYPE FURNACES," LOS ANGELES, CAL., APRIL 25, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

R. J. C. Wood: I notice here it says one-third of the energy is used in radiation losses. If the radiation loss amounts to one-third of the working amount, I don't see how they could get 97 per cent efficiency.

R. W. Van Norden: I cannot answer the question exactly but I imagine that what Mr. Elwell means is the furnace or transformer efficiency. Taking into consideration the heating of the hearth, it would not have that efficiency. There are no published figures on the furnaces on the Pitt; there are no induction furnaces there and I don't believe they intend to install any as they are very well satisfied with the electrode type. They are not the Heroult furnace, but a modification of an earlier type which the operators have worked out themselves. I can not give any figures on operation and costs. I understand that refined pig-iron can be laid down in San Francisco at $18 a ton, or less.

Earl W. Paul: I am slightly familiar with the process of reducing iron ores and the making of steel by the Bessemer and open hearth processes, and know how important it is that the product of the furnaces should show a uniform chemical analysis.

From the data given in the paper it appears that the product of the electric furnace runs remarkably uniform, and further that at small cost the iron or steel can be kept in a molten condition and treated until the desired chemical analysis is obtained.

Another very important feature, is that, the chilling of the furnace is not a serious matter. Should the furnace chill, the current can be turned on the solid mass and in a few hours is remelted. The chilling of the present type of furnace, usually means quite a serious loss.

J. J. Frank: I had occasion during the last week to visit one of the large steel manufacturing companies, and I saw an arc furnace and discussed it with one of the attendants, and he remarked that the handling of the electrode is one of the most difficult things. It was a Heroult furnace. When the carbon drops off into the bath, it of course affects the chemical analysis. The attendant also told me that while the steel produced met the chemical analysis, it did not always live up to the same physical requirements; that is, the results vary.

I am a little familiar with the induction type furnace, and I would like to add to the remarks of the author by saying that there is a type of induction furnace in which the primary winding is a hollow tube. This primary is supplied with current from a transformer stepping it down from 10,000 volts or any other voltage which may be available. Water flowing in this copper tube keeps it cool, so a very high current density is possible, and it will influence the operation of the transformer because of its increased weight. One of the objections to the arc furnace,

Digitized by Google

whether it is the Heroult or any other furnace, is the heat from the furnace affects the reliability of the induction motor operating the electrodes. At first glance, that is not very important, but when you consider that any fumes which pass off naturally ascend and if the induction motors are directly over the furnace the fumes will influence the insulation and the action of the induction motors, it is more important; and that, I believe, is one of the serious problems in the construction of these arc furnaces; namely, to take care of and protect the induction motors from these fumes.

Another problem is the installation of the induction motors and the gearing that is necessary. The induction motor must be clamped directly to the electrodes, and that must be the potential of the furnace. Another objection is, in an arc furnace, the arc may create high frequencies, which being transformed to the high potential side of the transformer, affect the operation and may disturb the whole system so that it may induce stresses in the transformer which cannot be foreseen until the operation is begun.

H. H. Sinclair: Are the furnaces mentioned treating pig iron into steel? I had the impression, and I would like to ask Mr. Van Norden if it is not true that in the works of the Noble Steel Company, they were treating iron ore and converting it into pig iron.

R. W. Van Norden: There is no attempt to refine the iron. Pig iron only is made from iron ore.

H. H. Sinclair: What type of iron ores do they get, magnetic ore or one of the others?

R. W. Van Norden: It has a high percentage of iron, about seventy per cent.

H. H. Sinclair: I think that they treat a magnetite ore in Shasta County.

J. J. Frank: With the induction type of furnace it is possible, as I stated, to use a transformer scaling down from any high voltage to the primary of the furnace and that primary charge might be a very minor one and is copper through which water circulates and the insulation is just rubber hose. The problem there is a very simple one.

Another point raised here is the variation of the voltage. That may be very readily done in the induction type by an ordinary regulator. It would make it very easy to regulate and momentarily give 200 per cent overload current if it was desired to very rapidly heat the charge.

R. W. Sorensen: In connection with this kind of work I believe there is one feature the effect of such a load upon the supply source which must be carefully considered. The author states that a better load is put upon the line when the induction furnace rather than a furnace of the electrode type is used, but has not called attention to the fact that with the use of the electrode type of furnace it is impossible to balance the poly-

Digitized by Google

phase power line except by means of a motor-generator set which changes the polyphase current to either single phase alternating, or direct current; because of that old rule " a single phase current pulsating power cannot be turned into an equivalent polyphase current, or *vice versa*, without some rotating devise which will balance the transfer of energy."

Another point in favor of the induction type of furnace is that there is less liable to be such rapid fluctuation of current as will probably occur with the electrode type when there is any change in position of electrodes or in the conducting property of the charge. Suppose your electrode moves slightly. If you have, as the author states, 6200 amperes, for instance, and the voltage produced by the varying of that current is anything like what we have with transmission lines or was mentioned a few moments ago, *viz.*, 200 times the current interrupted, you would have a tremendous amount of power that would have to be taken care of somewhere. Now suppose your current varies but ten per cent, that would still leave you something over a hundred thousand volts to be taken care of in what is probably a low voltage system. Of course, it is very probable that the voltage variation in the supply transformer will not be anything like the voltage thus induced on a line but on the other hand it may be more. Just what law this would follow I don't know, but I am quite sure that a transformer for this kind of service should be made especially for this service because if these larger variations take effect on transmission lines, a certain percentage of that voltage variation must take place where you have magnetic circuit in the transformer, so if you are going to use transformers, for such service, special care should be exercised or you will have trouble with your transformers supplying to electrodes such large current as 6200 amperes.

C. W. Koiner: In addition to what Professor Sorensen has just stated, I would add that these furnaces operate to give the companies additional field in which to sell current. In 1904, we are told there were only four electric furnaces in existence, and they were in Europe. Today we have over one hundred, ranging in size from 100 lb. to 15 tons. These are used in this country and in Europe. There has been a furnace in operation in South Chicago for the past year or so and I understand it gives very good results. We are also told that current is now being sold at off-take periods for the refining of steel at a cost of about one cent per kw-hr. This has been going on for about a year. The cost is very reasonable when you consider it in comparison with the cost in refining operations.

Budd Frankenfield: It seems to me we along the Coast here should be especially interested in electric furnaces, not for the smelting of steel particularly, but electric furnaces in general. I would not regard it as an off-take proposition, because in furnace industries such as we have at Niagara, they operate twenty-four hours in the day. They have a large enough load factor to keep up a continuous demand for current.

Digitized by Google

Another thing is the large amount of power that can be used by these furnaces. For instance, it would not take a very large plant in some electrochemical or electric furnace industry to use the entire Owens River power which we expect here, to found an industry and employ men, instead of spending a great deal of money for a general distribution system. I have no doubt there are plenty of raw materials on the Pacific Coast to be utilized in making furnace industries, such as are in existence in Europe, a good proposition and a success.

C. H. Vom Baur: The Kjellin induction furnaces being put out today are chiefly of the small, laboratory sizes, as the Rochling-Rodenhauser electric induction furnaces have three distinct advantages over the Kjellin, which give it undoubted preference as follows:

1. It operates on polyphase current and in the one and two-ton sizes at 50 or 60 cycles with a power factor of 0.7 to 0.8.

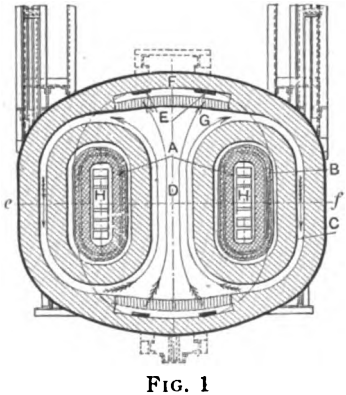


FIG. 1

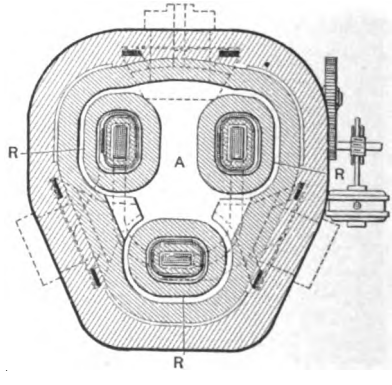


FIG. 2

2. Owing to the different shaped hearth, that is, having two or three intersecting circuits making a large hearth in the center, as shown in Figs. 1 and 2 herewith, and on account of the auxiliary, secondary current which is usually 30 per cent of the whole, which also goes through the bath, the so-called "pinch effect" or interruption of the circuit is absolutely precluded. This was one of the greatest disadvantages of the Kjellin furnace.

3. The larger hearth thus made allows a *rapid* refining of steel.

One of the greatest advantages of the induction furnace not mentioned by Mr. Elwell is its aptitude for thorough deoxidation of the metal and absence of segregation.

Relative to the magnesite lining, improvements have lately been made so that this now lasts three weeks instead of two weeks as formerly.

One of the metallurgical features, not mentioned, which is of some moment as it saves time, is that the power and thence the maximum heat remains on the furnace when rabbling off the

Digitized by Google

slag. In an arc furnace the carbons have to be withdrawn for this operation.

As Mr. Elwell assumes that current is made for $20 a kw-yr., it is hardly possible that current would be used all the time and the practical probability is that the current would be in use not over $\frac{2}{3}$ or $\frac{3}{4}$ of the time, costing therefore 33 or 50 per cent more per kw-hr. It would perhaps have been better if Mr. Elwell had also added the cost of the usual ferro alloys and fluxes, such as lime, roll-scale, etc., to the conversion cost for the sake of completeness. These fluxes and additions usually cost from 60 cents to $1 per ton.

The summary of costs of production inclusive of fluxes, taken at $1, and allowing for actual cost of electricity, at 50 per cent increase, would more nearly be as follows:

1.5-ton furnace melting scrap and refining to pour high grade steel for castings. Per ton	$9.61
2-ton furnace refining molten converter steel to high grade steel. Per ton	4.22
5-ton furnace refining molten converter steel to high grade steel. Per ton	3.49
7-ton furnace refining molten converter steel to high grade steel. Per ton	3.18
7-ton furnace refining molten converter steel to high grade rails. Per ton	2.39

C. F. Elwell: The efficiency of 97 per cent refers to the electrical efficiency of the transformer. The core is built up of slightly heavier iron than usual and these laminations are separated by sheets of India paper. The core and copper loss in the primary is under these circumstances about 3 per cent. Similar electrical losses, not radiation losses, in the arc furnace are very much greater. The high resistance carbon electrodes dissipate a large amount of energy. It is true that the radiation loss is high as evidenced by the amount of power necessary to keep the furnace from freezing over a period of rest. The arc furnace is notorious for its radiation for in my experience it was very difficult to keep a top on one, and without a top the heat in the furnace room was unbearable. One point in favor of the Rochling Rodenhauser furnace is that most of the bath can be well covered to prevent radiation as it is unnecessary to remove the covers except for relining.

In reply to Mr. Sinclair, the iron ore in Shasta county has an analysis as follows: Fe 69.9 per cent; Fe_3O_4 89.4 per cent; Fe_2O_3 0.3 per cent; Mn O 0.18 per cent; Mg O 0.3 per cent; $Si O_2$ 2.4 per cent; P 0.011 per cent; S 0.009 per cent.

Considerable pig iron has been made but as yet the furnace does not last long enough to bring the cost per ton for furnace relining to a reasonable figure.

Professor Sorensen sounds a note of warning which it might be well to heed even if some of us have had no trouble from this source. I have had experience with 22,000 amperes and the whole load has been dropped suddenly many times but no ill effects have been noticed in the transformers.

Digitized by Google

DISCUSSION ON "ELEVATOR CONTROL." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR JULY, 1911.)

(Subject to final revision for the Transactions.)

Fred J. Newman: I want to ask the author of the paper what is considered high efficiency for worm gearing, also what the characteristics of the efficiency curve would be in regard to speed and tooth pressure. What would be the increased efficiency by use of ball bearings for end thrust?

S. N. Clarkson: Most central stations have a limited direct current area, and the tendency is for large office buildings to extend beyond the area of direct current distribution. It would be very interesting therefore to hear Mr. Barnum's experience with alternating current elevators, both with the wound rotor type motors and the squirrel cage motor with starting torque approximately equal to the pull out torque.

Theodore Varney: I wish to ask a few questions with reference to Mr. Barnum's paper. I think one of the speakers made an inquiry in regard to suitable controllers for alternating current elevator motors, I wish to ask Mr. Barnum if he has had success with such controllers for the higher speeds?

Referring again to Mr. Barnum's paper, I would inquire whether the slow speed points, where he uses a resistance in series with the armature and a shunt resistance around the armature, are entirely hand controlled, or whether he uses automatic relays for regulating the slow down, and if so, whether these relays are adjusted to the load on the motor at the time?

T. E. Barnum: I have no figures on tooth pressure, and very little data on the efficiency of worm gears. On one machine where a single worm and gear is used, with a ball thrust bearing, the efficiency from the motor to the load is about 75 per cent. With a standard worm gearing and collar thrust bearing on an overhead traction machine, the efficiency would be about 60 to 65 per cent. There are, of course, many factors of general design entering that would modify the conditions of operation and the efficiency.

Regarding the saving of energy, it is desirable to open the shunt field circuit if the elevator is to stand idle for any length of time. Where it is inconvenient for the operator to go to the service switch, it is possible to arrange very simply for the remote control of the main line switch. This arrangement is desirable in many cases where the machine and controller are at the top of the hatchway, and the operator leaves the car at the bottom landing.

The paper gives some information regarding the possible saving of energy under operating conditions when the shunt field circuit is partially excited in the "off" position of the controller.

The subject of alternating current elevators is a large one and it is difficult to answer briefly. I do not know of any high speed alternating current elevators. The principal difficulty in the way of a high speed alternating current elevator is that it

Digitized by Google

is not possible with the present commercial polyphase motors to obtain speed control regardless of load. For this reason the elevator must be stopped by the mechanical brake alone, and this device is very unsatisfactory where the speed is high. The high speed alternating current elevator will not be satisfactory until we can get, with the polyphase motor, the equivalent of the field control and dynamic brake of the direct current motor. As far as acceleration is concerned, the alternating current motor will give as satisfactory results as the direct current motor, provided that the alternating current motor rating is not pushed up so far that the starting torque is close to the break down torque.

Answering the other question about slow speed, the control of this speed is manual by the operator from the car switch. With the worm gear machine there is no automatic adjustment of the armature shunting resistance, although the closure of the armature shunt circuit depends upon the counter electromotive force. With very high speed gearless machines, there is an arrangement described in the paper for the adjustment of the slow speed resistance to take account of some variations of load in the car. This automatic adjustment is necessary on high speed elevators in order to be able to set the limit switches so as to stop the car at the end landing with maximum load, and also have a satisfactory stop at light loads.

Digitized by Google

DISCUSSION ON "CHOICE OF ROTOR DIAMETER AND PERFORMANCE OF POLYPHASE INDUCTION MOTORS. CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR MAY, 1911.)

(Subject to final revision for the Transactions.)

E. F. W. Alexanderson: Mr. Hoock's paper gave a valuable contribution to the literature of induction motors, not in the sense that it will enable the designer to produce better motors or even enable them to save time in doing so, but from the educational point of view. The value of Mr. Hoock's paper, to my mind, is his method of dealing with the proportions. The problem for the designer is very much circumscribed by practical conditions, and his work consists in compromising between those conditions. Therefore, in order to do so intelligently, he must have a clear conception of the effect of any change in proportions and if he has such physical conception, it is not necessary to use any formula or curves; in fact he would not have time to do so. If Mr. Hoock had written the paper for parties who have an outside interest in induction motors rather than designers, he probably would have formulated his theories somewhat differently. However, there are a number of points that ought to be of general interest. I particularly refer to what he calls the leakage coefficient. The leakage coefficient, according to his definition, is the ratio of magnetizing current to the ideal short-circuit current; and this factor is most important of all proportions of induction motors. I think the name of "leakage coefficient", although it may have some precedence in literature, is rather inadequate, because it does not convey to the mind of the general engineer the features of practical importance which it is intended to signify. If it is stated that, in a certain induction motor, the short circuit current is twenty times the magnetizing current. this statement contains complete information regarding power factor and over-loading capacity. More often the motor is described by saying that the short-circuit current is seven times the full-load current, and this information does not mean anything unless it is coupled with other information on magnetizing current or power factor. The ratio of short circuit and magnetizing current are inherent characteristics of the motor, whereas the ratio of short-circuit current and full-load current are characteristics of the designer's method of giving the motor a commercial rating. I believe it would be of advantage if the practical significance of the so-called "leakage coefficient," that is, the ratio of short circuit to magnetizing current were more generally known and appreciated, because it makes it possible to furnish almost the complete information as to a motor excellency in power factor and overload characteristics by stating only one figure.

C. J. Fechheimer: The author makes a statement near the beginning of the paper as follows:

"It is fully demonstrated by tests that the $D^2 L$ of standard speed motors is not limited by the temperature rise, but by the performance and flux density."

Digitized by Google

He then follows this by subdividing the investigations under the following headings:

1. Leakage coefficient.
2. Copper losses.
3. Overload capacity.
4. Iron losses.

This would convey the impression that these are the only important limitations to be considered in choosing the diameter. I do not agree with him in the statement that the temperature rise does not affect the $D^2 L$, and believe that in a great many motors this should influence the choice of dimensions at least as much as the performance and flux density. He has not considered the effect of the diameter and length upon what I believe to be one of the most important considerations in proportioning motors; that is, the cost. For example, in most 25-cycle and many 60 cycle motors we have no difficulty whatever in obtaining reasonably high power factors, efficiencies and torques, but we find that we would have to use a very great amount of copper to keep the temperature rise within the specified limits, if at the same time we were to obtain just enough torque. In extreme cases, moreover, such design may involve the use of very deep slots in the stator; to such a degree that, for a given internal diameter, we can increase the number and size of conductors, (thereby increasing the flux), and use shallower slots, and thus obtain the same, or possibly a smaller external diameter than with the larger number of conductors. As the heating in the majority of standard speed motors is nearly entirely dependent upon copper loss, it will be seen that for a given temperature rise, the section of conductor is proportional to the number of conductors. Hence, for the same heating, the weight of copper will be practically proportional to the square of the number of conductors. Therefore, the small flux motor has a large amount of copper and a prohibitively great cost. In other words, in many standard speed motors, *temperature rise*, *cost* and *flux density* are the limitations placed upon the dimensions of the motor and not performance; but in some motors, *performance*, *flux density* and *cost* (not temperature rise) are the limitations.

Now, when we come to consider the effect of the diameter and length upon the cost, we shall find that in general the large diameter motor is more expensive than one of small diameter, even though the active material, in the two motors be the same. This will be apparent when one considers the great increase in weight in mechanical parts, such as the yoke and shields, and the increase in labor with the increase of external diameter of the stator punchings. We cannot go too far, however, in decreasing the stator diameter (and increasing the length) for after a certain point is passed, we obtain a machine of such length that a great increase in active material would be required to obtain the desired performance and temperature rise.

From the above it follows that the performance, temperature rise and cost are related to the diameter and length to such an

Digitized by Google

extent that we cannot neglect any one of these factors in deciding upon the proportions of the motor. While it may be possible to reduce the relations of the many quantities involved to the form of mathematical equations, the final expressions are liable to be so involved and complicated that they would scarcely admit of solution.

In proportioning the parts of squirrel cage induction motors the importance of the effect of diameter upon the losses, which it is possible to obtain at starting for a given temperature rise, should not be lost sight of. It can quite easily be shown that the temperature rise of the conducting material in the rotor circuit is dependent upon the watts per pound of conducting material and the specific heat of this material. This is based on the assumption that all the heat which is generated at starting is absorbed by the material in which it is generated.

It is also well known that the starting torque, expressed in synchronous kilowatts, is equal to the kilowatts lost in the rotor circuit. Hence to obtain high starting torques and at the same time keep the temperature rise within reasonable limits, it is necessary to have a large amount of conducting material in the rotor circuit, as we are limited by the specific heat of this material.

We cannot put too much loss in the rotor bars, as this would result in high temperature rise in the rotor circuit under operating conditions, thus causing undue temperature rise in the stator. In a great many motors we must therefore place most of the loss in the end rings. Assuming a definite specific heat and resistivity of the material to be used in the end rings, the loss in the rings can be increased in proportion to the square of the diameter for the same loss per pound of material.

We would of course increase the loss in the end rings without prohibitive heating at starting by increasing the specific resistance of the material used, which would increase the section and thus enable use of a smaller diameter. This, however, becomes a very serious objection in many cases, as the end ring assumes such huge proportions that the ventilation is seriously impaired. In this, as in nearly everything that the designing engineer has to decide, he must rely upon his judgment for the choice of the diameter as affected by the loss in the rotor.

S. Haar: Mr. Hoock prefixes to the curves of his paper a description of the circle diagram for determining characteristic curves and of the leakage factor as a design constant. In the use of which he follows the general practice in Europe. Here, in the United States, the analytical methods of design and calculation are still in use, which in my opinion are the only ones suitable for the designer in commercial practice. Had Mr. Hoock spoken from the point of view of a teacher or a lecturer before a mixed audience, it would be idle to take exception to his methods because in such a case there would be no question of the results being used in a contract; however, the introductory paragraphs of the paper express the hope that the curves deduced

Digitized by Google

will be useful for the layout of a line of motors, and for this reason I wish to dissent from his methods.

I have investigated every circle diagram which has come to my notice and have yet to find one which always gives reliable results. While the circle diagram is useful for approximating extended characteristic curves or for demonstration purposes, it must always remain an approximation because it is fundamentally wrong. The magnetizing current does not remain constant, and the locus of the end of the current vector is not a circle, as I proved by determining analytically the centers of circles drawn through successive groups of points. Short arcs of the locus may strongly resemble a circle, but neither the centers nor the radii of the successive circles remain constant. Since the determination of part load power factors by the circle diagram is easier than by the analytical approximations, the lack of a thoroughly reliable circle diagram is regrettable. To my mind, one reason for the confidence in the circle diagram is its trial on motors with high power factor and efficiency; for such motors, almost all methods of approximating give good results. Unfortunately, however, some of the motors which are built have low power factor; here the rapid approximations fail so that just when reliability is most needed, the accuracy of a circle diagram is most uncertain.

Furthermore there is no saving of time in most cases. Four points or at most five will determine satisfactorily the characteristics of a motor between half load and 50 per cent overload. A five point curve can be calculated by a person of average skill with a slide rule within an hour, and an unusually rapid calculator can reduce this time to about 40 minutes. In order to secure an accuracy comparable with the analytical method, a circle about 20 in. in diameter is necessary and by the time the diagram is laid out to scale just as much time will be consumed. In the occasional case when the characteristics throughout the whole range of motor action are desired and exact values are not necessary, the circle diagram saves time.

The system of calculations of either Dr. Steinmetz or Professor Pender seems to give the same results; after a trial of both I find practically no difference in the time required. One great advantage of the Steinmetz method is that the whole calculation can be carried out with only a slide rule, while it is necessary to have tables of some of the factors employed in the Pender system. It may be objected that the theory of these methods is difficult of comprehension. This argument does not apply as calculators unacquainted with the theory have no difficulty in obtaining correct results. All that is necessary is to tabulate the successive steps and follow the order systematically.

The leakage coefficient by definition involves both the magnetizing current and the leakage reactance; these vary in quite different manners and the difficulty of their predetermination is not at all the same (it is comparatively simple to calculate the magnetizing current); why then use a factor containing two

Digitized by Google

independent variables when one will accomplish the same purpose? The leakage coefficient is no more constant than the leakage reactance; if it is necessary to calculate either one, the same assumptions are used, and if data from tests are at hand, the same readings in either case will give the necessary information. A designer using the leakage coefficient would probably draw the diagram for the purpose of obtaining the maximum torque and maximum output of a motor; whereas by the use of very simple formulæ involving the resistance and reactance, these characteristics can be calculated in a few minutes.

Experience indicates that short cuts such as the curves presented in this paper will be of moderate value only to any one except the author because their aim (selection of motor dimensions to meet certain guarantees) is not the chief criterion by which the dimensions usually are decided, and furthermore because motor design is an art and not a science. By this I mean that the arbitrary assumptions, such as the spread of flux in the gap, the length of coil ends, etc., differ enough among designers that it would be necessary for every one using the author's methods to refigure the curves to suit his own particular practice. It usually happens that a motor must be developed from patterns and dies already existing; therefore the first approximation will be from the frame of something already built which would have the rating desired at the speed given. The next point, in my opinion, is to settle the maximum output. After this come the choice of copper densities and finally the efficiency and power factor. It is my experience that a satisfactory design can be arrived at more quickly by this method than by starting from the $D^2 L$. This constant must be used with considerable discretion, and I should prefer to consider it only as a check on other methods. For determining the gap diameter, a good beginning can be made by choosing the number of slots per pole per phase and tooth pitch by judgment to conform to the guarantees expected, and selecting the nearest practicable diameter.

It is the exception rather than the rule, however, that motor builders are called upon to meet definite guarantees, and it is probable that as time goes on, the custom will die out. In the early days of motor drive, when power plants were smaller and the cure for troubles from low power factor was not so generally known, high power factor was demanded, and the motors were relatively expensive. Nowadays, it is frequently more economical to use smaller motors of lower constants and adopt additional means for obtaining a satisfactorily high power factor; in the future this tendency will probably increase.

Theodore Hoock: Mr. Feehheimer emphasized the importance of cost analysis in induction motor design. When I tried several years ago to combine the cost data with the machine dimensions, I obtained such complicated formulæ that they were evidently not fit for practical use. This was chiefly due to the inactive material which is usually a large percentage of the total

Digitized by Google

factory cost. A quite accurate estimate of the cost can easily be made by means of a set of curves showing the cost of the different parts in ratio of the outside and inside diameter of the punchings, core length, voltage, number of poles, type of winding, number of slots, and so on.

Mr. Alexanderson's remarks as to the adaptability of the derived formulæ, I refer to the statement in my paper. "The derived formulæ are not intended to supersede the detailed designed but they should be used for the first lay out."

The main object in presenting these investigations, was to study the relation of the different items of the performance. There are only two publications to my knowledge on the subject of minimum leakage. Hobart* published curves showing a constant decrease of the leakage coefficient when the core length was made smaller. The influence of the end connection caused this mis-leading conclusion. While Professor Arnold† derived the opposite result, that is an increased ratio of core length to pole pitch should decrease the leakage. We see however that there are distinct minimum values which may be obtained from equation 11 and 12.

I made the statement that the $D^2 l_i$ of standard machines is not limited by the temperature rise. There are certainly exceptions. A definite limit cannot be given on account of the influence of construction and ventilation. In case blowers are used to cool windings and cores, the temperature limits will seldom be reached, (at reasonable speeds) but the air gap density will cause disturbance. Either the iron losses will effect the efficiency (open slots) or prohibitive magnetic noise may be the result. I mean the objectionable hum, howling or whistling of machines which eliminate their applications in hospitals, apartments, hotels or offices.

We have at the present time no systematic investigations on this subject neither on alternating current or direct current machines and only cut and try methods in connection with experience are available. The prediction of noise with certain slot combinations is very uncertain. There are many other sources for magnetic running or starting noise as the amplitude of variation of the air density, field form, rotor currents, unsymmetrical windings, loose punchings, weak yoke iron, mechanical and electrical resonance etc. Fundamental research work on magnetic noise should be well worth while to be undertaken by advanced students. Any results on this subject will be appreciated highly by the designing engineer.

Mr. Haar discussed in length a part of my paper, which is in no way connected with the main scope of it. The superiority of analytical over graphical methods for commercial work is open for discussion. The preference to either one is chiefly a question of personal taste. The circle diagram has proven success. It might be interesting to note that ap-

*H. M. Hobart, St. Louis, 1904. A. I. E. E. TRANSACTIONS.

†E. Arnold. *Wechsel stromtechnik.* Vol. V.1., p. 343.

Digitized by Google

proximately 30 to 40 per cent of all induction motors built in the United States are designed or guaranteed on the basis of the circle diagram. I personally use either one or both methods whenever the problem demands it. The advantage in using the leakage coefficient or its reciprocal value is brought out in my paper and by Mr. Alexanderson.

The accuracy of the results obtained by the slide rule or circle diagram is practically the same. It is, furthermore, not justified to condemn a method because its inaccuracy in a problem in which the first assumption cannot be predetermined or vary within 5 to 10 per cent. The argument that a calculator who is unacquainted with the theory can obtain correct results when using the slide rule only is in my mind no proof in favor of the analytical, but for the graphical method. A number of lines can easily be drawn and its construction memorized, but the large number of equations have always to be looked up in order to avoid mistakes. On the other hand, I consider it a dangerous procedure to take calculated or graphically obtained results from a person who is not acquainted with the theory.

The results of my paper are based on correct scientific investigations and since art (motor design) is an applied science I do not see why a designer could not use the results in the table given in the Summary to great advantage.

Regarding the remarks of Professor Nies, I can only say that I go through the same steps that he does with the exception that I avoid the complication of two sine functions. Furthermore, he neglects in the cited example the increase of the magnetizing current due to the slot opening and saturation of the iron. Taking these points into consideration his method of calculating the magnetizing current is quite correct.

J. D. Nies: I believe that the following is a simpler method of determining the wattless magnetizing current than that used by Mr. Hoock.

Let B_{ave} be the average density in lines per sq. cm. in the gap, or

$$B_{ave} = \frac{\text{flux of one pole}}{\text{area of one pole}}$$

Let h be the ampere-turns required to project this flux density across the air gap of $\triangle$ cm. depth, or

$$h = \frac{B_{ave} \triangle}{0.4\,\pi}$$

this being the average value of the sinusoidally distributed m.m.f.

Then the wattless magnetizing current per circuit is

$$I = 1.16 \frac{h \sin \frac{\pi}{2 N_{sp}}}{n_c \sin \frac{\lambda \pi}{2}}$$

Digitized by Google

in which

N_{sp} = slots per pole in the stator.

n_c = half the conductors per slot, or turns per coil in windings having as many coils as slots.

λ = pitch expressed as decimal fraction of full pitch.

$$1.16 = \frac{\pi^2}{6\sqrt{2}} = \text{constant used for three phase motors.}$$

$$(1.23 = \frac{\pi^2}{8} = \text{constant used for two phase motors}).$$

I = effective amperes per circuit, *i.e.*, in a ring connected motor with two parallel circuits per phase, (I) would be the effective current in one circuit only, and the star or line current would be $I \times 2 \times 1.73$.

An example may be taken from Hobart's Electric Motors, Page 421, 1904 edition, where dimensions and tests of the following motor are given:

Horse power	100
Volts	500
Phases	3
Cycles	50
Poles	12
Stator slots	180
Stator slots per pole	15 (N_{sp})
Air gap	0.15 cm. ($\triangle$)
Turns per coil	1.5 (n_c)
Pitch is full	1 (λ)
Connection	star
Circuits per phase	1
Area of 1 pole	625 sq. cm.

Calculation:

Flux per pole 1,480,000 lines.

$$B_{ave} = \frac{1{,}480{,}000}{625} = 2{,}370 \text{ lines per sq. cm.}$$

$$h = \frac{2{,}370 \times 0.15}{0.4\pi} = 283 \text{ ampere-turns.}$$

$$I = 1.16 \frac{283 \sin 6 \text{ deg.}}{1.5 \times 1} = 23 \text{ amperes effective star current.}$$

This result agrees exactly with the tested value as quoted by Hobart.

The above method follows the logical order for such calculations, since it begins with finding the flux density, next the ampere-turns necessary to produce the density, and finally the amperes to give the ampere-turns. Besides being extremely simple the method is exact under all conditions.

Digitized by Google

DISCUSSION ON "COMMERCIAL LOADING OF TELEPHONE CIRCUITS IN THE BELL SYSTEM." CHICAGO, JUNE 28, 1911 (SEE PROCEEDINGS FOR JULY, 1911.)

(Subject to final revision for the Transactions.

E. H. Bangs: One of the most valuable features of Mr. Gherardi's paper is its frank admissions in regard to the practical limitations of circuit loading. In the past there have been some extravagant claims made for the possibilities of this practice, and this paper, in its description of the actual results obtained in the best practice is most welcome.

Mr. Gherardi answers, in a way, a question that has been put to me on several occasions by engineers experienced in power transmission as to why it was that the telephone engineers did not long ago take advantage of the common knowledge of the power transmission engineers, on the subject of added inductance. In asking this question the power engineers say, in effect, "We gave you the idea. All that you had to do was to work out the details." This statement contains its own answer, an answer which is illustrated by Mr. Gherardi's paper. As a matter of fact, it has taken from 10 to 15 years of very earnest effort on the part of a number of people to simply "work out the details." Telephone transmission is only power transmission in its most minute form, and of course the same laws apply to both methods of conveying energy. The difficulties encountered have not been found so much in applying known laws, as in perfecting practical details, and the ingenuity displayed in simply that portion of the problem relating to the loading of phantom circuits and the phantoming of loaded circuits is of a high order. I think that the development of this whole problem has proceeded with dispatch, along logical lines, and abreast of, or well in advance of the economical demand for its solution.

F. B. Jewett: While there is not much that I can add to what Mr. Gherardi has said on the subject of commercial loading of telephone circuits in the plant of the Bell system, there are one or two points which I think may be of interest to those who are not familiar with loading. One of these is with regard to the mathematical development which forms the foundation upon which our present loading practice has been built. All of our experience has tended to confirm this mathematical theory and so far as I am aware it is entirely rigorous. Although the first results on actual loaded circuits seemed not to agree with theoretical expectation, we soon learned that discrepancies which existed resulted from a lack of reliable data as to line constants at high frequencies and not to any imperfection in the mathematical theory of loading. With increasing knowledge as to the high frequency constants of different classes of circuits, the discrepancies between the computed results and the results of actual transmission tests are each day becoming less, and the theoretical forecasts more amply verified.

Mr. Gherardi shows that the general equation for the attenuation constant, which involves the four factors, series resistance,

Digitized by Google

series inductance, shunt capacity and shunt conductance or leakage can be greatly simplified by the elimination of the last of these constants. In the early stages of our work it was assumed that on both cable circuits and open wire lines having high insulation, this could be done. Later work showed us, however, that the direct current insulation was not necessarily a criterion for the high frequency shunt conductance even in the case of open wire circuits where dissipation of energy in the dielectric would, at first sight, seem to be almost negligible.

High frequency measurements during the last few years on both open wires and cable circuits have given us values of the shunt conductance which, when substituted in the general formula, tend to bring the computed and measured attenuation constants into close agreement. I have every reason to believe, therefore, that when we are able to determine the four line constants at high frequencies with the accuracy with which we can now determine direct current resistance, capacity and insulation, we will find that the formulæ used in our computation work are rigorously in accord with the results of actual observations on loaded lines.

The other point which I wish to mention briefly has to do with the enormous change which the introduction of loaded circuits has brought about in the terminal apparatus and outside plant, both in the original installation and in the matter of maintenance. The deleterious effect of low line insulation is so much more pronounced on loaded circuits than on non-loaded circuits that the introduction of loading on a large scale has necessitated a very much higher grade of line maintenance than was ever found necessary in the case of non-loaded circuits even of large gauge. Also in the case of any extensive loading, especially on cable circuits, the necessity of placing a large number of loading coils in the plant has made it absolutely essential that the loading applied to the various circuits be such as to give a resultant plant of maximum simplicity. It was early seen that any general attempt to engineer the loading for each particular line so as to give maximum efficiency to this line would result in a plant that was unmaintainable on account of its complexity. The result has been that for both open wires and cables a system of standard loadings has been developed and the loading of any particular circuit is that standard which most nearly conforms to the theoretical best loading.

In the case of cable loading, especially on congested runs where a great number of circuits are to be loaded, it is very desirable that the loading coils for all circuits having a given type of loading be placed at the same points. This factor has reacted on the art of cable manufacture to the extent that all cable for loading is now manufactured to meet a standard capacity requirement irrespective of gauge or the number of conductors in the sheath —the standard capacity being that which will result in the lowest annual charge on the loaded circuits of given efficiency.

Digitized by Google

Also the fact that the sending end impedance of loaded lines is very much larger than for non-loaded lines and varies greatly with the type of loading, with resultant high and variable reflection losses, has meant that we cannot connect loaded lines together and to non-loaded lines in the indiscriminate fashion permissible with non-loaded circuits. We have, therefore, been forced to design our loading so that the circuits of various character, whether loaded or non-loaded, may be connected together or to the terminal apparatus with the minimum amount of reflection loss. Further the necessity for having max mum circuit flexibility in a large and growing plant has made it imperative that all loading be planned with the view to future growth and the necessity for avoiding special operating practices as much as possible.

Although a great step in advance has been made since the first introduction of loading on commercial circuits, there is still a large amount of development work to be done before we have succeeded in deriving all of the benefits possible from the use of inductance coils on telephone circuits.

E. H. Colpitts: I wish to call attention to one or two features connected with loading; that is, the necessary engineering studies and scientific investigation in connection with the application of loading are making telephony, from the standpoint of line transmission, an exact art.

Ten years ago when the rule for loading was first given us by Professor Pupin, the only method of determining whether a certain piece of apparatus introduced into the telephone line would cause a transmission loss or a transmission gain, was to actually make a transmission talking test over the circuit. When the art of loading was introduced it was recognized that much more refined methods of measuring the electrical constants of telephone apparatus and telephone lines under the electrical and magnetic conditions of telephone service must be developed. It was seen that actual telephone currents could not be employed, but that it would be necessary to employ alternating currents of telephonic frequencies and amplitudes. At that time no high frequency generators had been designed which would satisfactorily deliver the necessary high frequency currents. Therefore, one of the first problems the telephone engineer had to undertake was to design high frequency generators capable of delivering alternating currents at frequencies of from 200 to 3,000 periods per second. In order to employ this current in the methods which seemed most practical and desirable it was necessary that the open circuit electromotive force of these generators should be as nearly as possible free from harmonics. Such generators were designed.

Among the problems of a physical nature which confronted the telephone engineer it was necessary to devise methods of measuring accurately the losses in iron and its various alloys when subjected to magnetizing forces as small as 0.005 c.g.s.

Digitized by Google

units and when fluctuating corresponding to alternating currents at frequencies of from 200 to 3,000 periods per second. The telephone engineer today is able to measure such losses with a high degree of accuracy. The engineer had to devise methods of measuring losses in dielectrics at the telephonic frequencies which I have mentioned and at the low potentials which are involved in actual telephone transmission.

In addition to this, methods of measuring very accurately the inductance and effective resistance of loading coils were developed. The measurement of inductance accurately in terms of inductance standards is not at all difficult, but the measurement of effective resistance with a small current and at a high frequency requires most carefully designed apparatus and a complete knowledge of all the factors involved, many of which factors it would seem at first sight to the ordinary engineer could be neglected.

In connection with loaded lines themselves, as Dr. Jewett has already indicated, we soon found that we had to take account of facts which had hitherto been neglected. As an instance, it became evident that we had to measure accurately and consider the effect of bridged impedances on the efficiency of loaded circuits; whereas, in case of unloaded circuits the effects of such bridges could very generally be neglected. Also, in the design of cables which are to be loaded it is very important that electrical symmetry or balance be preserved, and the engineer is interested in capacities and differences of capacities as small as one-millionth of a microfarad in lengths of 400 or 500 ft. of cable. He can today measure and take account of these small differences in capacities between the wires of one pair and the adjacent pairs.

So far I have referred merely to measurements upon the elements used in loading. A large amount of work has been done in connection with the development of methods of making measurements upon telephone circuits, in order to determine the various terms involved in their transmission efficiency. I mention these merely as illustrations of the general nature of the development work necessary to the present condition of the loading art.

E. B. Craft: It may be of interest to note some features in the construction and design of the loading coils themselves. The art of constructing inductance coils is an old one. The use of inductance coils in loading, where we must deal with currents of very high frequency, however, involves a consideration of details and methods of reducing losses to a point which I doubt is reached in ordinary practice.

As an example we may consider a coil such as is being used in loading the new New York-Washington underground cable circuits. The core of this coil consists of a toroid built up of approximately 90,000 turns of No. 38 gauge iron wire. To reduce losses each of these turns must be insulated from the

Digitized by Google

other. This in itself was a problem of considerable magnitude and it eventually led to the development and use of an insulating enamel coating having a thickness of less than 0.0005 in.

In working out the design of the coil windings we also had to consider means for reducing losses, that led to departures from ordinarily used methods. In order that the copper losses might be reduced to a permissible figure, the conductor was subdivided, using a number of strands of enamel insulated wire, which, in turn, were insulated in the usual manner to provide a stranded copper conductor. The winding itself was then subdivided into sections to properly control capacity balances between adjacent sections of the windings.

In the construction of the coil such as we are using in the New York-Washington cable there is required a total length of 2½ miles of copper wire wound around a core composed of 30 miles of iron wire. The mechanical problems involved in the application of these windings were quite difficult. Toroidal coils have been used in the past and were usually wound up by hand, involving a great deal of time and labor. In order that coils of this type might be turned out in large quantities on a commercial basis, it was necessary to develop special machinery by which these windings could be applied automatically. This has resulted in a considerable reduction in cost and increase in efficiency.

After the cores are prepared and the windings applied, it is necessary also to give consideration to the proper control of the losses in the dielectrics. This has led to the application of refined methods of manufacture in the way of vacuum drying and impregnation.

Consideration of the amount of material used in their construction will indicate that, when completed, these loading coils are of no mean proportions. As they are applied to the line or cable they are usually grouped in pots or cases similar to transformer cases, and the larger cases containing 21 coils weigh in the neighborhood of 2,000 lb. and because of size and weight are usually located in the manhole of the subway.

Various speakers have dwelt upon the necessity for adhering to accurate mathematical methods in calculating the electrical constants of the completed circuits, and the development of the design of the coils themselves has reached the stage where we can, by the application of proper methods of calculation, predict with certainty the various electrical characteristics of the completed coil. When we consider that these electrical characteristics involve not only the ohmic resistance and inductance of the coil, but such factors as capacity unbalance and alternating current conductance as well, it can be seen that it has been necessary to employ methods that have not heretofore been commonly used in the design and construction of inductance coils for various commercial uses.

Allard Smith: It might be of interest to get a brief idea of how we have applied loading in conjunction with the A. T. & T.

Digitized by Google

Co. engineers to a large telephone system like there is in Chicago. We have developed a comprehensive loading plan for the entire city, and have advanced the work under that plan as rapidly as conditions would permit. Briefly, only 16 and 19 gauge cables in Chicago are loaded, although there is one cable which carries 14 gauge loaded conductors between Chicago and Milwaukee.

Radiating out from the Chicago Telephone Co's. toll building, in the center of Chicago, there are six loading paths, and these paths bring into the center of Chicago the trunk and toll lines from the outside and outlying exchanges. All of the work is underground. We have no aerial loading because the lines going out into the country are not long enough.

There are distributed around Chicago about 10,000 loading coils, which load about 19,000 pair miles of wire. These coils are incased in sealed iron pots and are placed in manholes, spaced one mile and three-quarters apart, except the coils on the Chicago Milwaukee cable, which are placed one mile and a quarter apart. These cables run out north as far as Waukegan, with 16 gauge conductors, and with 19 gauge conductors to Evanston—about 12 miles. Waukegan is about 25 miles.

Another cable runs south to Hammond, about 25 miles, with 16 gauge conductors and 19-gauge conductors as far as South Chicago, about 16 miles. Also one directly west, going to Maywood, with 16 guage conductors; another southwest, along the C. B. & Q. R.R. to La Grange; another directly south to West Pullmann. All of these cables bring the 19 gauge pairs from the outlying Chicago exchanges within a belt line, say, four to five miles out from the city, into the toll board. The 16 gauge conductors bring in the exchanges still further out called the "neighborhood exchanges" and the immediate suburban exchanges. Now we are just starting another loading path, which will be a belt line, continuing in a radius between exchanges about five miles from the center of the city.

J. G. Wray: I would supplement what Mr. Smith has said by stating that in Chicago if our trunk lines were not equipped with loading coils, it would be impossible to carry on commercial conversations between offices on opposite sides of the city. If loading coils were not available and there were no satisfactory substitute, it would be necessary to provide over-head open wire construction for trunk lines between such offices. Such construction would involve high pole lines with many cross arms, would congest the streets and alleys and make them unsightly and would add greatly to the cost of construction and maintenance and would provide a less satisfactory service than is provided at present. As a matter of fact, it would be physically practically impossible to provide pole lines enough to carry the open wire construction which would be necessary.

The problem of local telephone transmission in a big city like Chicago or New York would be exceedingly difficult if it were not for the loading coil. I believe that this fact is not generally

Digitized by Google

realized by engineers who have considered the advantages of the loading coil usually, from the standpoint of long line transmission such as the New York-Denver circuit which Mr. Gherardi has just described.

The problem of telephone transmission in a big city, I think however, has hardly received the attention that it deserves.

Frank F. Fowle: One of the very earliest practical tests of Dr. Pupin's system of inductance loading was made on a 670-mile circuit of No. 12 N. B. S. G. (173-lb.) open wire (hard drawn copper), in 1900. The coils then employed had an ohmic resistance of 9 ohms, an inductance of 0.225 henry and a shunt capacity of 0.0042 microfarad. These coils had no iron and were enclosed in wooden boxes, filled or impregnated with an insulating compound. They were spaced $2\frac{1}{2}$ miles apart. Comparative transmission tests conducted during clear dry weather showed that this loaded circuit was substantially equal to a non-loaded circuit of No. 8 B. W. G. (435 lb.) open copper wire.

The successful result of this trial gave immediate impetus to the development of better loading coils, with the result that the original type was abandoned in favor of the coil described by Mr. Gherardi. In coils of the type now used extreme precautions are necessary to keep the effective resistance at a minimum and not in excess of the resistance stated in the paper.

It is interesting to note that the toroidal coil finally developed is identical in its form with Faraday's original experimental transformer, which consisted of a simple iron ring with two windings, one on either half of the ring.

Quite extensive loading was soon undertaken on commercial circuits, but two prominent difficulties arose. The first was the effect of lightning, which necessitated the development of suitable protection. The second arose from low insulation. It was quite generally assumed at first that the leakage conductance, S, could be neglected, as Mr. Gherardi points out. But it developed that this was not the case. This fact was not clearly demonstrated until several thousand miles of line had been loaded and the commercial operation had shown clearly that during extremes of wet weather the insulation of open lines was inadequate. The reasons for this are clear both mathematically and physically.

This trouble affected the No. 8 circuits most, because they had lower resistance and impedance, non-loaded, than No. 12 circuits and were therefore more efficient initially. Being the more efficient circuit to start with, the gain due to loading was relatively less and the injurious effect of leakage was felt sooner.

Substantial improvements in line insulators did not follow for several years and then glass was abandoned in favor of glazed porcelain.

Experiments were also carried on in relation to the effect of different spacings, varying from two miles to eight miles. It was found that there was little or no gain by short spacing and heavy

Digitized by Google

loading, because the gain secured by increased inductance was practically nullified by the increased apparent resistance of the coils. This will be seen by comparing the apparent resistance of the coils with the resistance per mile of No. 8 conductors.

It was first pointed out by the writer that the proper location of coils with respect to cross-talk disturbances was every eight miles, at the junction of 8-mile transposition sections, or every *S* pole in Barrett's 1898 standard transposition system. This fact, taken in conjunction with the advantages of light loading in respect both to the effects of leakage, and the cost of installation, led to the adoption of the 8-mile spacing.

The increase in cross-talk as a result of loading is the direct consequence, in a large measure, of the increased transmission efficiency, which increases the volume of cross-talk as well as direct talk. At the same time the relative proportions of electrostatic and electromagnetic induction are disturbed and the former is increased. This necessitates increased attention to the electrical balance of loaded metallic circuits, both in open wires and cables. Barrett's earlier system of transposition, known as the A B C system, has certain untransposed exposures and in some cases will permit considerable cross-talk between non-loaded circuits, so that its use is not to be recommended. The standard system of 1898 contains no untransposed exposures, and in general is much superior to the early system.

The use of loaded circuits undoubtedly calls for a high standard of maintenance, and increases the maintenance expense in comparison with non-loaded circuits. While this slightly diminishes the net commercial gain secured by loading, it presents no particular difficulties and its consequences need not be feared.

There is a lower limit of line length which it pays to load, just as in the case of cables. Therefore loaded circuits cannot economically be cut up into short-haul lines, for use part of the time. Equally true, loaded circuits should not be connected to intermediate or way stations, both for the reason just given and further because bridged impedances are of harmful effect on loaded circuits in general.

Some difficulty was experienced with the coil shown in Fig. 1, of the paper, from magnetization caused apparently by telegraph currents when a loaded circuit was composited. Morse currents in either side of the coil magnetized it at once, of course, and in some cases set up a permanent flux which impaired the properties of the coil telephonically. The dividing current of the simplex system was much less harmful, tending only to pole the core at opposite ends of the diameter dividing the windings. The coil shown in Fig. 7 prevents any magnetization by the simplex, through its balanced arrangement of windings. There is probably some advantage in using a polar duplex on either side of the composite, because of the very frequent reversals in the direction of current.

Bancroft Gherardi: Professor Shepardson has asked a question concerning the connecting of loaded cable circuits with

Digitized by Google

open wire circuits. As I understand the question it refers to what special arrangements, if any, are needed when loaded cable circuits are to be connected to open wire lines. Is that the question, Professor Shepardson?

G. D. Shepardson: The question in my mind is whether you use the transformer or use the tapered loading to minimize the reflection.

Bancroft Gherardi: In general we do not do either. There are practical difficulties in the placing of terminal transformers at the outer end of underground cable circuits; there are also a large number of practical difficulties brought in by undertaking to taper off the loading of a circuit. One of the greatest of these difficulties in connection with tapering off the loading would be the extensive changes and re-arrangements which would become necessary from time to time as it became advisable to increase the length of the loaded cable involved, or otherwise change the layout of circuits. Suppose you had a cable that ran out five miles and later was going to be extended two miles more. In case the loading on this cable was tapered there would be a variation in the inductance of the loading, the spacing, or both. When, however, the cable was to be extended, substantial changes would have to be made in the loading coils and their arrangement. In general, we aim as far as possible, to load open wire circuits and cables so that the sending end impedance on the different classes of circuits will be the same, and so that the spacing of the loading coils on the two types of circuits are relatively the same electrically, that is to say, the relative spacings bear a definite relation to the relative electrical characteristics of the two circuits. If these conditions are attained there are no reflection losses where loaded underground cable circuits are connected with loaded open wire circuits. In practice these conditions are so nearly attained that the reflection losses in the case mentioned above are negligibly small.

The discussion of this paper has taken so much the form of a statement of additional facts in regard to loading and so little question has been raised in regard to any of the points brought out in the paper that I do not see that I can add anything in closing except to thank those who have participated in the discussion for bringing out many points of interest in connection with the subject which for the sake of keeping the paper down to a reasonable length were either omitted from the paper or only touched upon briefly.

Digitized by Google

DISCUSSION ON "THE HIGH EFFICIENCY SUSPENSION INSULATOR." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions.)

E. E. F. Creighton: The fact has been brought out a number of times during the past year that the great problem at the present time in high tension transmission is really confined to the line, and is a matter mostly of protection against lightning on the line. Personally I have a great admiration for the work the author of this paper has done in perfecting insulators. Although the methods used differ from the methods of observation used in the lightning arrester laboratory, Mr. Austin gets, apparently the same result. I have not had an opportunity to read the entire paper, but have personally talked with Mr. Austin about his methods of observation, and as I see them, they consist in observing the successive flooding of the insulator parts by brush discharge when the potential is gradually increased. In that way the relative stresses can be observed over the different parts of the insulator. In the lightning arrester laboratory the rela-

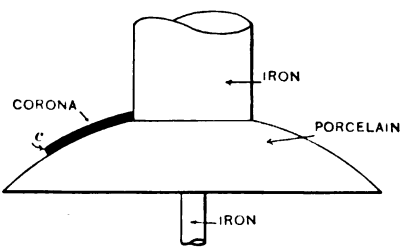


FIG. 1

tion of potential to puncture and potential to flash around the skirts of an insulator is determined by a sudden discharge from Leyden jars with a frequency approximating about one million cycles per second.

Since the problem is not dielectric strength for dynamic potential, but the protection against lightning, it is important to have tests that will give an indication of the effect lightning will have. The ordinary method of testing insulators, that is, gradually applying potential, does not give any indication of what the insulator will do under lightning stresses. This point has been brought up before. To illustrate, if this is the porcelain disc (see accompanying illustration Fig. 1) and the potential is applied between the top and the bottom, and is gradually increased, the effect is to produce corona streamers which run out more or less from the terminals, and before the spark takes place the distance between the terminals has been very materially reduced, so that one might say that the spark took place from some point *C* out on the skirt of the insulator around to the

Digitized by Google

other terminal. Now, when a high frequency of anywhere from 500,000 to 3,000,000 cycles is applied to the same insulator, the discharge has to jump the entire distance from metal to metal around through the air or puncture the porcelain. I have made many tests on the pin type of insulator. One example will suffice for illustration. By putting on gradually applied potential at 60 cycles, an insulator flashed around some 500 times. An electrostatic charge was then discharged against the insulator, and it punctured immediately. The methods used by Mr. Austin, watching the gradually growing brush discharges, makes it possible to observe the weak parts individually and to increase the dimensions of the porcelain accordingly, so as to prevent puncture. I tested some of these insulators recently, and a thousand charges were discharged against a single disk, of such a value that they would just not spark around. I wanted to see if there was any possibility of fatiguing the material, and so far as I could see, there was not. By raising the discharge potential slightly, it would spark around the insulator each application. Unfortunately, we have not been able to get enough static potential to spark around a string of these insulators in series.

So far as the surface resistance is concerned, I believe it has comparatively little to do with protection from lightning—I am speaking of such a thing as a slight accumulation of dirt on the surface. Although I have not tested out this particular feature, similar tests with high frequencies show there is very little decrease in the equivalent-needle-gap by using high resistance in parallel. There is one other point, and that is regarding the multi-gap effect—it has been commented on many times, and has been tested by a number of engineers.

There is no doubt from the consideration of Dr. Steinmetz's theory, on the multi-gap arrester which was developed in 1906, that the same conditions exist to a greater or less extent in the suspension type of insulator, and it is quite sure that some types of these insulators will spark very much easier on high frequency than on low frequency. In regard to this, it seems to me that the conditions shown in Fig. 10, would illustrate that it is possible to make a design of these suspension type insulators, in which the multi-gap effect has entirely disappeared. Dr. Steinmetz showed at the time he made his investigations that the multi-gap effect in a multi-gap arrester depended upon the value of the capacity between cylinders relative to the capacity of each cylinder to ground. If the capacity from the cylinder to ground was diminished, then it was possible to do away entirely with the multi-gap effect. The subject was further developed by Messrs. Rushmore and DuBois a year later, and all that material is available at the present time and might be profitably used. In connection with the design of these insulators, referring to Fig. 9 and Fig. 10, I think it is evident that Fig. 9 would give less multi-gap effect than the insulators in Fig. 10.

Digitized by Google

In closing, I should like to ask Mr. Austin if he has noted any fatigue in insulators, whether there is any possibility that an insulator under test will be damaged. It is an important thing to decide, in order to be able to test insulators installed on a line to eliminate faulty ones at times of service when their failure would do the least amount of harm. I know in one case of apparent fatigue of a 100,000 volt insulator. When it was first put on the line, it was entirely quiet, but after it had operated for several months, it became noisy and finally broke down.

Paul M. Lincoln: I have not read this paper carefully but I notice that Mr. Austin has devoted considerable attention to the question of leakage, leakage current and leakage resistance paths of insulators. It becomes important, in the design of insulators, to determine whether the equipotential surfaces are determined by the question of leakage over the resistance paths of an insulator, or whether it is determined by the question of condenser capacity. For instance, these suspension insulators are in effect conductors which are separated from each other by some insulating material. Line potential is applied at one side and the ground potential is applied at the other side. Now, the total potential is distributed across this whole combination, and the ideal insulator is the one in which the potential is equally distributed across the various units and the individual sections of each unit. When that condition is obtained, we have the ideal condition. It becomes important to determine whether the potential of the equipotential surfaces is determined by the current which leaks across the resistance paths, or whether it is determined by the condenser capacity between the equipotential surfaces.

Now, there are some facts which have been observed which to my mind indicate that the potential of these surfaces is determined almost entirely by the static capacity, and very little by the leakage over the resistance paths. The main fact that so indicates is that some insulators, and in fact many insulators, will have a flash-over voltage wet as nearly as high as when dry. What does that mean? A wet insulator undoubtedly has a much lower resistance over its surface and consequently a much higher leakage current than a dry one. Further, the distribution of potential due to these leakage currents must be different when wet than when dry, since surfaces previously dry are now wet. As a consequence, one would expect to have the distribution of potential and the flash over voltage different in a wet insulator than in a dry. The fact that there is practically no change in the flash over voltage between a wet and a dry insulator would indicate that the equipotential surfaces are determined by static capacity rather than by leakage across resistance paths.

P. H. Thomas: I would like to add one item to Mr. Creighton's explanation of the multigap effect, so called, illustrating how important it is. There was a transmission line put up, I

Digitized by Google

think about 1900 in Colorado, in which lightning arresters were placed out doors in boxes, the arresters being of the multigap type, and they were placed in as small boxes as possible in order to economize space. It was a 20,000-volt line. The gaps connected in the two line wires, as I remember it, were placed in "V" fashion—ground connection being at the point and one line being connected to each leg. For some strange reason, it seemed strange then, the arresters would not hold the line voltage, they would "slop-over", as it was called, extremely easily, much more so than in the laboratory or in other installations. The reason for this is clear. The capacity of cylinders connected near one line, on account of the proximity of the cylinders connected to another line, is much greater than it would have been if isolated—that is the minute charging currents were greater. This condition makes no trouble in the first cylinder, because it is connected directly to the line, but the second cylinder and the others have to receive their small charges by drawing sparks from these cylinders connected to the line so that the current in these gaps is greater, when you have two closely adjacent cylinders connected to opposite lines. This condition caused a great deal of actual trouble. I have forgotten at this time what the solution of the difficulty in this case was, but in 1902, I repeated some experiments to prove the correctness of my theory above stated which is substantially the same as outlined by Professor Creighton. In the experiment cylinders were taken and arranged in a "V" shape upon a board. A very much larger number of units would be jumped by a given voltage in this arrangement than when the cylinders were arranged in a straight line. I think the factor was as great as 2 to 1, the difference between the two arrangements being due to the lesser charging current taken by the cylinders in the straight line arrangement than in the arrangement in the V form. I think this experiment was described in 1905 at the Asheville Convention. It is a matter of importance, not only in the cylinders of lightning arresters, but in all types of electrical apparatus. If you want to be free from sparking trouble, such as jumping over surfaces on bushings, and other such conditions, keep your high potentials as far apart as possible.

For instance, in an ordinary insulator where the ground potential we will say is carried by the pin up pretty close to the conductor, there will be a much greater tendency to jump over the petticoats than if the insulator were made entirely of porcelain and the ground and line wire widely separated.

E. M. Hewlett: We investigated this insulator trouble, and we found right away that the parties who were interested wanted to know a great deal more about the disk insulator than they had found out about the pin insulator, in fact, more than they have found out as yet. We made practical tests. We assumed that if we could get porcelain of the proper dimensions and thickness to withstand puncture—to flash over rather than to punc-

Digitized by Google

ture—that that was the safest line to follow. Since that time some insulators have been made larger than they should be, that is, they are likely to puncture before they flash over. It seems to me that the best design possible is to make them so that they flash over rather than puncture, and also to space them closely enough together so they will flash over the whole set rather than individually, to bring the arc over and around the disk.

In reference to the fatigue of porcelain, a good many persons consider there is a fatigue in porcelain, but what is often considered to be fatigue, I think is low burning. The porcelain is not thoroughly vitrified, and for a time it stands up satisfactorily. The dampness is absorbed and then the strength is decreased and the insulator will consequently puncture. It would seem therefore that the best general plan would be to make the disk small enough and of good enough material, high enough grade of material, and well enough vitrified, so as to resist puncture. Shape them so they will stand a maximum weather test, and not be reduced too much on the line test, and then use enough disks in series to get the desired result. I think with a small diameter of disk there is much less likelihood of puncture from the lightning as the path of the lightning does not deviate so much from a straight line in going to the ground.

N. J. Neall: Where does the analysis of punctures per minute begin, and, further, is the record of a given batch of insulators after installation of value in this connection? I have seen failures on the test table which seemed to indicate imperfect material. I think there would be a point where the imperfect material would be dismissed and the criterion Mr. Austin selected would begin?

A. O. Austin: There is probably no appreciable fatigue in good porcelain under normal electrical stress. The puncturing being due to mechanical defects or poor material.

When an insulator punctures the effect on operation is the same regardless of the cause of failure, and it matters little whether there is fatigue in the material; the number of failures for a given stress and time, however, is of great importance. With an increase in the dielectric strength of insulators the percentage of breakdowns due to stresses above those which may be shown on the time breakage curves, diminishes rapidly and the time breakage curves become valuable in predicting failure when comparing different insulators.

If a number of insulators are subjected to stress and the rate of puncture becomes less with time, the insulators can hardly be said to show fatigue for the remaining insulators have improved in reliability. If, however, the rate of puncture increased with time, the insulators may be said to show fatigue for the reliability has decreased. Then for practical purposes it may be said that there is no fatigue unless the puncture rate increases with time and applied stress. These characteristics can be

Digitized by Google

shown without going out on the line, and should form the basis for dielectric strength and reliability.

The distribution of stress between the several parts of an insulator may vary widely for different conditions, and it is possible to design an insulator such that the flashing potential is higher under storm conditions than when dry. It was found that too much space would be required to discuss stress distribution, an example, however, will show how the electrostatic capacity and the surface resistance may effect the performance under different conditions.

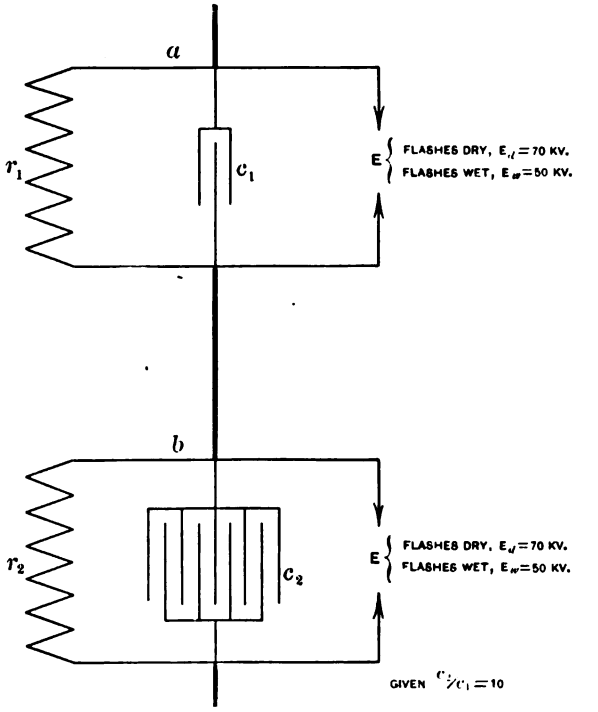


FIG. 1

The accompanying illustration Fig. 1 represents two insulating elements in series, each element having an electrostatic capacity C surface resistance r and flashing potential equivalent to E_d for dry conditions and E_w for wet conditions.

For dry conditions, r_1 and r_2 are very high and the leakage current may be neglected the stress distribution being determined by the members acting as electrostatic condensers.

For this condition a carries 9/10 of the stress and flashes when the voltage applied to the series reaches 78 kv.

When a flashes, the arc forms a shunt reducing the stress on

Digitized by Google

a and increasing it on *b* and by increasing the stress on the series by a few kilovolts, the series flashes. The capacities may easily be made large enough so that 85 kv. will cause complete flashing.

When the insulator is wet, the surface resistance may be so low that the surface leakage current will determine the stress distribution. If the elements have practically the same surface resistance the stress would be the same on each part and the flash-over of the series would be 100 kv. which is higher than the dry flashing potential.

The electrostatic capacity, surface resistance and flash-over vary greatly with a change in conditions. It is difficult to predict the performance of an insulator except for limiting cases, which is usually sufficient as the intermediate conditions are less severe.

The effect of design on depreciation was given considerable attention in 1904 as it was seen that where the surface current was large the insulators coated very rapidly. This was largely due to the accumulated material left by the water, upon being evaporated by the current. Where the evaporation is large the washing action of the rain is practically eliminated and the insulator will depreciate rapidly.

In some designs the charging current increases very rapidly with a slight surface depreciation. To eliminate this, the all porcelain designs shown in Fig. 4, were made. Since there was a considerable difference in potential between the upper and lower surface of the flange it formed a condenser with a comparatively large charging current, the performance being considerably below that expected until the electrostatic capacity of the flange was reduced by the addition of petticoats. By making the insulator with discs with low electrostatic capacity the presence of the metal connection was not so noticeable and compared favorably with the best all porcelain types.

The stress distribution under the high frequency surge may be quite different than that at normal frequency, even at flash-over of the insulator. Insulators which have a small air path for the forming of the arc between line and ground, will be much better protected than those having a long air path, although the insulators may have the same flashing potential at normal frequency.

It is a question as to how much insulation is needed for the extremely severe conditions on the line. A consideration of the different characteristics will probably lead to an increase in the dielectric strength over what it is at the present time.

Digitized by Google

DISCUSSION ON "PROBLEMS IN TELEPHONE TRAFFIC ENGINEERING." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR AUGUST, 1911.)

(Subject to final revision for the Transactions).

A. P. Allen: The "problems of telephone traffic engineering" used to be to *guess what was going to happen*—and we are only just a little bit better off today. As I listened to some of the other papers, I wanted to congratulate the light, power, and construction engineers because they could fix at least something and depend on it. This paper is, however, comforting to a man in my position, because it gives the idea that even in telephone traffic engineering things are coming around so that you can depend on them; so that you can say that an average operator's load ought to be so much, and expect to get it; you can say that the public will give you more calls between nine and ten in the morning than they will between three and four in the afternoon, and have it come true.

But in practice almost everything that the traffic engineer touches goes back on him sooner or later. He gets figures that show that the normal load in a city residence district is heaviest in the morning, and some day he gets the larger load in the middle of the afternoon—larger than he ever had in the morning. That is something that we cannot control. It is the same way with the handling of the toll traffic. The business between two towns will be, perhaps, only 15 per cent taking place in the busy hour, while the business between other towns that have apparently the same conditions will be 25 per cent in the busy hour. It is very hard to establish standards, or formulae, that you can depend upon on all occasions, when the conditions simply *look* similar.

A few papers out of my files illustrate that point. For instance, in Chicago, the long distance business—making a series of tests every day for one week: on Tuesday the busy hour, in the afternoon, was 103 per cent of the busy hour in the morning. (Of course we have to plan our operators for the busy hours.) The very next day the afternoon busy hour was only 64 per cent as heavy as it was in the morning. In the same way with long distance traffic of New York City, comparing different months. Taking April as 100 per cent; one year, the August business is 91 per cent while the next year it is only 85 per cent; but in both years December is 110 per cent of the April business.

All such figures demonstrate that the use of the service by the public is very uncertain. We get up formulas and say that if the average holding time is two minutes and fourteen seconds, a group of ten trunks will carry so many calls. As a matter of fact, our average is not a reliable average, because the variation between the shortest and the longest connection is very great. The formula holds true *if* they were all nearly alike, as to the average time; but as they are plotted out, they run from five-second calls up to about ten minutes. Can we, under such conditions, accurately foretell how many trunks we will need to give

Digitized by Google

instantaneous service to a given number of patrons? That is what we have to contend with in city traffic: we have to give instantaneous connection: we cannot wait for circuits. Between two offices a certain number of calls will require a certain number of trunks; between two other offices the same apparent load may take nearly twice as many.

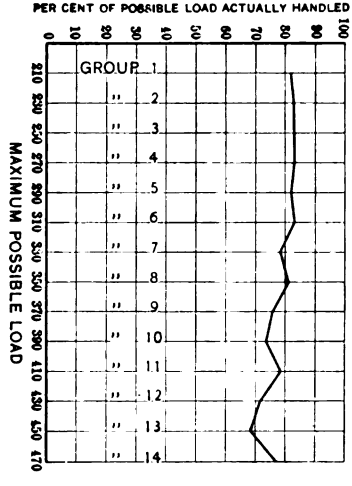


FIG. 1

The charts shown in Figs. 1 and 2 are original, perhaps—at least I have never seen anything just like them. They show the "guessing" we have to do on the ability of the average operator. Each line represents roughly, a group of operators, graded as to what they can do in fifteen minutes, and also showing what

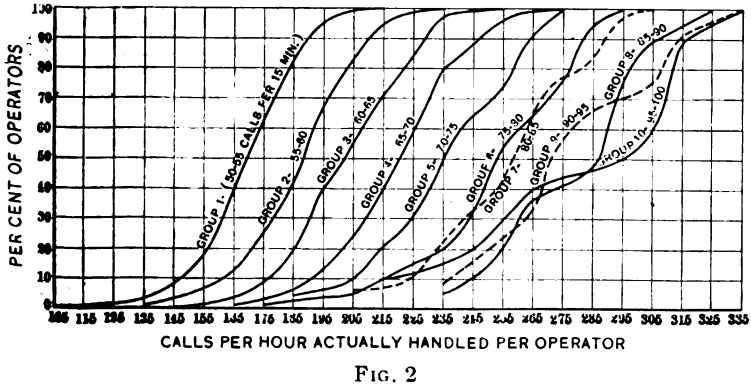


FIG. 2

they did do in the total hour. A total of 1250 operators were thus analyzed, their ability being represented by what they did in fifteen minutes. It is reasonable to suppose that they could do four times as much in an hour if they had it to do; and that

Digitized by Google

the fluctuation in their hourly load is due to the fact that the total loads vary so much during an hour. Due to that fact, the per cent of efficiency that all grades give is almost exactly the same. Girls that handle 55 calls per quarter hour reach 82 per cent efficiency for the total hour. Girls that can handle 50 per cent more in 15 minutes have only the same relative efficiency for the total hour.

I certainly hope that Mr. Valentine's paper gives the right idea, that in the end we will be able, by analysis and careful tabulation and watching of results, to get some real, accurate data on which to base fundamental plans; but it does not appear to me that we have yet reached that condition. And a great many of the problems that we have to contend with are not within our control at all—that is, they depend entirely upon the use of the service by the public.

W. Lee Campbell: In manufacturing, mining, bricklaying and similar occupations great advances have been made in the last few years by engineers studying efficiency methods and making motion studies with the idea of increasing the efficiency of the individual operator. To one who has been familiar with this, the question naturally occurs what can be done along this line, or what has been done in manual telephone work toward increasing the efficiency of the operators? I suppose the principal difficulty is in supplying each operator with as much work as she can do. As Mr. Allen has just brought out, in one moment the operator may have all she can do; the next moment she may not have as much as she can do. The result is that if standards were set, the operators could not be compelled to come up to them by force, nor could they be coaxed to come up to them by increased remuneration. Consequently, it would appear to me that if some device should be introduced between the subscriber's lines and the operator, which would furnish her with work at the greatest speed she could take it, as determined scientifically, that the operators could be brought to a very much higher standard of efficiency. The work could be distributed, starting at one end of the board, to the operators as far as it would go and at the other end of the board a certain per cent of operators could be kept for emergencies. I am not a manual telephone engineer, but I should like to ask of some of these gentlemen who are, if there are not possibilities in such a scheme.

Bancroft Gherardi: I feel that we are all very much indebted to Mr. Campbell for raising the question which he has and for pointing out to us such an interesting problem concerning traffic engineering. It is a most valuable illustration of the type of problem which traffic engineers are sometimes confronted with because it requires not solely the work of traffic engineers, but also the work of plant engineers and requires the coöperation of these two sets of engineers to obtain satisfactory results. The traffic engineer can point out what kind of call distributing system he would like to have from an operating standpoint, and the

Digitized by Google

results which he would expect such a system to attain. Based upon this, the plant engineer would undertake the design of suitable apparatus, and would, in general, sooner or later be confronted by some traffic requirements which could not practically be met or which could only be attained at such great cost or such excessive complications as would not be warranted. So the working out of this problem and similar problems requires coöperation between the traffic engineer and the plant engineer in order that from the general idea at first proposed there may be finally evolved the best arrangement, taking into account all of the circumstances of the case—operating savings, maintenance, character of service, first cost of apparatus, etc. While a discussion of the specific problem which Mr. Campbell has mentioned would carry us somewhat beyond the scope of this paper, I might say in reference to the matter that while a good deal of work has been done on this question by a large number of people and extending over many years, so far as I know no large application of the principle of call distribution has ever been made anywhere. I do not feel that we are now warranted in saying that we can ignore this problem and say there is nothing in it. It is my opinion at the present time that it is a problem which has not as yet been worked out and that there is certainly no data available at the present time to permit us to give an affirmative answer to the question "Is call distribution a satisfactory and economical feature of a telephone switchboard?"

Mr. Valentine has, I think, placed us all under obligations to him in presenting to us his paper dealing with traffic engineering problems. While traffic engineering does not deal with volts and amperes, and in that sense is not electrical engineering, it is nevertheless a most important and interesting class of engineering work, the nature of which is but little appreciated at the present time except by those who come in direct contact with it in their work.

A. P. Allen: What I wanted to make clear was that, regardless of any system of distributing, no one can tell in advance what the load is going to be—that is, how many calls the public is going to give to us—at any particular period of the day; and even if we had a perfect distributing system for those calls, we would not know whether to put on one set of operators, or more, in order to give a certain grade of service.

W. Lee Campbell: It is found in manufacturing practice as shown by the studies of Mr. Harrington Emerson, Mr. F. W. Taylor and others, that the efficiency of the average operator paid by the day, is only about 67 per cent of what is attained if an operator is paid in proportion to his or her efficiency. It is impossible to bring an operator up to the highest efficiency unless she is supplied with all the work she can do. The work must be, in some way, gauged and the operator must have before her definite standards to which she will be expected to rise. As Mr. Allen says, in the use of switchboard operators, the trouble

Digitized by Google

is that the public does not furnish a regular amount of work but if some of the automatic or mechanical devices should be used between the public and the operators to distribute the calls to each at her best rate of speed and the efficiency of the operators could thus be brought from 67 per cent up to 100 per cent, a great saving would be secured. A certain percentage of operators could be held to take care of the irregularities. With the present plan, each operator is given a fixed number of lines to handle, and consequently all of them are subject to irregularities, of load with the result that each has an excuse for not doing her best.

F. P. Valentine: While this discussion has brought out one or two typical problems which the traffic engineer has to face, it also indicates that there is not a general understanding of how far these studies have been carried. It is perhaps not generally known that for some years telephone traffic problems have been receiving constant study as the result of which many of the apparently intangible factors have been reduced to known quantities and their inter-relation established, so that due weight may be given to variations. The analytical work of the past few years has been merely outlined in brief form in this paper to point out that the work can be carried on intelligently having accurate knowledge of values and their relations.

We cannot today consider all the problems solved, but by the methods pointed out and with the facts and laws already established as a foundation the way seems fairly clear to the ultimate solution of the various elusive problems which constantly confront the traffic engineer. Traffic engineering in itself is a comparatively young branch of engineering work, in which developments have come very fast within the last few years, and in regard to which there is comparatively little knowledge or appreciation outside of the comparatively few who have been fortunate enough to participate in the comprehensive studies which have been carried on. It is safe to say that the developments of the next few years will bring about a better realization of the fundamental importance of the study of these problems as well as a better appreciation of the progress already made.

Digitized by Google

DISCUSSION ON " THE ECONOMICAL DESIGN OF DIRECT-CURRENT ELECTROMAGNETS." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions)

Frank F. Fowle: Mr. Wikander's paper is a very comprehensive discussion of the design of direct current electromagnets, limited to the types for comparatively heavy duty. Electromagnets for light duty, mainly in closing one or more local contacts, are used in tremendous numbers in telephony, telegraphy and signalling. Their design is probably as important commercially as that of the heavy duty type.

The problem broadly stated is to design magnets for minimum annual cost—or minimum interest, depreciation, taxes, maintenance and cost of operating energy. In the case of constant current circuits, or in circuits with an intermittent current of constant maximum value, the least energy is consumed when the resistance is a minimum. Again in the case of direct current telegraphy the question of resistance becomes doubly important, because it affects the efficiency and cost of transmission, as shown in the writer's paper on " Telegraph Transmission " presented at the Convention.

Mr. Wikander's expression (7) is identical with the writer's expression (134) in the paper just referred to above, or

$$P = \frac{\phi^2}{8\,\pi\,S} \qquad (1)$$

In the case of ordinary electromagnets such as those employed in telegraph relays and generally similar apparatus (numerous examples in telephone and signalling practice), the magnetic circuit is nearly closed and the air gap is normally short in comparison with its breadth. The poles are usually extensions of the cores and the armature is a flat piece of equal breadth, spanning from pole to pole in the familiar manner.

In such cases the reluctance of the whole magnetic circuit is ordinarily composed in great part—over 90 per cent—of the air gap reluctance. By neglecting the relatively small iron reluctance the writer shows that expression (1) can be put in the form

$$P = \left(\frac{16\,\pi\,n^2\,I^2}{800\,l^2}\right) S \qquad (2)$$

when $n\,I$ represents the ampere-turns and l the length of air gap. This shows that for a constant value of ampere-turns the pull increases proportionately with the cross-section of the air gap or with the area of the poles.

This is easily seen from expression (1): doubling the pole area halves the reluctance and doubles the total flux, while the flux density remains constant; thus B^2 is the same as before, but S has been doubled and therefore the pull P has been doubled also.

Digitized by Google

This result is not capable of being extended indefinitely, for when the pole area has been increased roughly ten times, the air gap reluctance is probably no longer the principal part of the total reluctance and then further increase of area has a rapidly diminishing value.

It is essential to observe that the enlargement of one pole, but not both, is of little or no value in case the one not enlarged is of controlling importance in its relation to the total reluctance. Thus the introduction of a third air gap may destroy the whole principle here described.

In order to determine whether polar enlargement will be generally useful, the criterion is as follows. Calculate the reluctances of those gaps across which the working attractive force is made use of, and then calculate the reluctance of the remainder of the magnetic circuit; if the former is several or many times the latter, then polar enlargements will increase the pull materially.

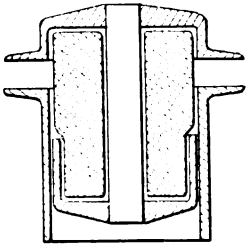


FIG. 1

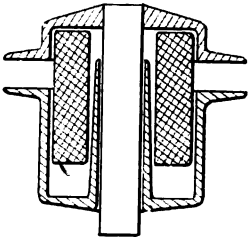


FIG. 2

Expression (2) can be written as follows:

$$P = \left(\frac{\pi}{50\ l^2}\right) (n\ I)^2\ S \qquad (3)$$

which shows that for a constant value of P, with increasing S, the ampere turns may be diminished in the ratio of the square root of the increase in S. That is, if S is quadrupled, the ampere-turns may be halved.

Figs. 10 and 11 of the writer's paper illustrate two methods of enlarging the pole areas, with telegraph relays. The enlargement, it may be noted, is relative and refers to the area of the pole with respect to the cross-section of the core. In the type of plunger magnets considered by Mr. Wikander there are several ways of securing polar enlargements. Two of these methods are shown in Figs. 1 and 2 herewith.

Charles R. Moore: This paper certainly marks a distinct step in advance along the lines of electrical design. Many electromagnets have been designed and their performance accurately predetermined, but the designer seldom knew without

Digitized by Google

carrying out several designs whether the one in hand was the best one for the purpose. The work oftentimes stopped without being carried to the point, where there was little doubt about a given design being the most economical for the work intended.

Increased attention is now being paid to the design of traction electromagnets on account of their usefulness in control apparatus. In order to make this kind of apparatus satisfactory, such considerations as efficiency, first cost, and space required must receive the careful attention of the designer.

Mr. Wikander by carefully analyzing the form of the equations resulting from the mathematical statement of the above considerations has been able to derive formulae giving at once the best and most economical dimensions, for a given design to fulfil a certain set of requirements. As one would naturally expect the cheapest magnet is not the most economical in the use of energy.

It is not surprising that the first publication of a paper of the type presented by Mr. Wikander should contain a few errors, and I wish to point out those that have come to my notice on first reading.

The equation $K_2 = \frac{e G_1 - G_2}{G_1}$ should read $K_2 = \frac{e G_2 - G_1}{G_1}$ to agree with equation (**28**), a similar correction should be made in the expression for cost.

The first term in equation (**15**) should read $I^2 = \ldots\ldots\ldots$ instead of $J^2 = \ldots\ldots\ldots$ and the exponent of P in equation (**52**) should be x instead of $2x$ as printed.

I am unable to check equation (**71**) and get therefor the expression

$$y = K_9 D^{\frac{5}{2} - 3x}$$

As given in the paper the exponent of D is $\frac{3}{2} - 3x$ which does not follow from the expression $2 - \frac{6x-1}{2}$, this being the exponent of D in equation (**70**).

This correction in the exponent of D makes necessary some important changes which I have endeavored to carry out as follows:

The quantity y which may express volume, weight or cost is a minimum when $\frac{5}{2} - 3x = 0$ from which $x = \frac{5}{6}$.

If this exponent be substituted in the equation taken as representative of the pull curves it becomes

$$P = K_5 t^{\frac{6}{5}} d^2$$

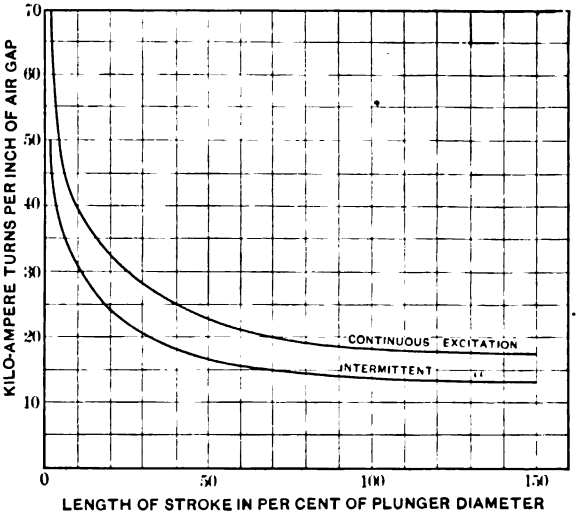
Digitized by Google

and the most economical flux density may be found from those parts of the pull curves which are parabolas of the degree $\frac{5}{6}$.

A tangent to any parabola of this degree intersects the y axis at a distance

$$y_1 = \left(1 - \frac{1}{\frac{5}{6}}\right) P = -\frac{1}{5} P$$

From Fig. 6 I have attempted to ascertain the most economical pull per square inch, in the same manner as that pointed out by the author but by using the tangents satisfying the equation just given. This pull I find to be about 70 lb. per sq. in. which is considerably different from the value of 27 lb. per sq. in., given in the paper.



I have replotted the curves given in Fig. 7 and present the same in the accompanying diagram. It will be noted that the curve for continuous excitation falls above, instead of below that for intermittent excitation.

Equation (**77**) should now read $P = 70 \frac{d^2 \pi}{4} = 55\ d^2$ giving $d = 0.135 \sqrt{P}$ for the diameter if the plunger instead of $d = 0.217 \sqrt{P}$ shown by equation (**78**).

After carefully marking out a value for z, equation (**97**) ($z = -\frac{1}{6}$). Mr. Wikander shows in equation (**100**) $z = -\frac{1}{2}$. This was done I presume on account of insufficient tests.

Digitized by Google

DISCUSSION ON "TELEGRAPH TRANSMISSION." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions.)

Bancroft Gherardi: Mr. Fowle's paper, which I have been asked to discuss, is one of particular interest, as it undertakes to present and to treat in a scientific manner a number of telegraph problems in the same way which has been so successful in dealing with problems concerning telephone work, power transmissions and electric light work. But few papers have been presented recently in this country which have dealt with telegraph problems as though they were controlled by the same physical laws as are the other branches of the electrical art. I have had so little time since I received the copy of this paper that I have been unable to study the mathematical proportion of the paper, but I have been over the rest of it, and the results which Mr. Fowle states have been attained in practice are, in general, in accordance with our experience.

The paper covers the subject from so many different aspects that it will be impossible for me, in the time to which my discussion is limited, to speak of many interesting questions which it raises. On two points, however, I should like to say a few words.

Mr. Fowle gives an interesting discussion of the problem of insulating telegraph lines. This is a very important question and one to which much study has recently been given in the telephone field, with the result that we are trying out a number of special designs of insulators, both of porcelain and glass. The paper suggests that a suspended insulator be adopted on certain telegraph lines. Much time and study will have to be given to this question before it is demonstrated that it will be necessary to make such a radical departure from existing insulator methods in order to obtain the desired results. A great many mechanical difficulties would have to be overcome in connection with the use of such insulators on telegraph lines, and it does not seem to me that it is as yet by any means demonstrated that we cannot, by the use of insulators of suitable material and suitable design, and supported on pins in the usual manner, obtain the desired results more cheaply and more satisfactorily than by the use of a suspended insulator. The suggestion in question is an interesting one, however, and I am very glad that it has been made, but it is my feeling at the present time that other and less radical methods are likely to accomplish the desired results.

The author's suggestion that much use might be made of copper steel wire for telegraph circuits raises at once a serious question in my mind. This wire has, I believe, in general, an ohmic resistance of about 2½ times that of hard drawn copper wire of the same diameter. It would, therefore, seem to me that the same reasons which have led the telegraph companies to so generally employ in their more important circuits hard drawn copper

Digitized by Google

wire instead of iron would deter them from employing a material which would represent a step backwards in this most important characteristic of a line.

Frank F. Fowle: The points brought out by Mr. Gherardi in relation to suspended insulators for telegraph lines I believe are well taken. The choice of a satisfactory insulator is necessarily a compromise between cost and efficiency, and on that score everyone seems to agree that the ordinary glass insulators now in service can be much improved upon. The question is how far we can go in the direction of better efficiency before the cost becomes too great—or in other words, where is the point of maximum commercial efficiency.

Before we can answer this question it is necessary to know what we can accomplish in improving the physical efficiency, without regard to cost. After settling that part of the problem, a cost study will fix the highest points of efficiency which is commercially feasible. My proposal for suspension insulators does not go farther than the first stage of the problem, and is along the line of obtaining the highest degree of insulation which is physically possible. An insulator of the suspension type is admittedly objectionable from a mechanical standpoint where the line wires are crowded together on the pole line, with the smallest feasible separation. On the opposite hand it seems to possess numerous advantages where the wires are, few in number, comparatively, and the climatic conditions to be met are severe. It is probably too soon to state any conclusions as to what forms and types of insulators will finally survive as commercially the fittest for various classes of telephone, telegraph and signal service.

Mr. Gherardi's remarks in relation to the use of copper steel wire—or as it is more familiarly known, copper clad steel—indicate that he is thinking principally of conductivity, without full regard for other requirements. Tensile strength is a factor quite as important as conductivity.

The commercial field for any conductor of a new type, such as copper clad steel, is necessarily a question of economics. The latter phase of the subject has not been treated in the present paper, but it will be found in somewhat extended form in my paper on "Line Conductor Requirements for Telegraph Transmission," read before the Association of Railway Telegraph Superintendents, at the annual convention of this year. The latter paper contains a full substantiation of the statement made by me in the present paper, that copper clad steel finds its economical field in the lines less than 300 miles in length, approximately, where no repeaters are employed. If automatic repeaters are made use of, the economical range of copper clad steel wire is limited only by the feasible number of repeater sets from an operating standpoint. One set will extend the range to about 600 miles and two sets to 900 miles.

The substitution of copper wires for iron by the telegraph com-

Digitized by Google

panies is probably traceable to several causes. The difficulty of maintaining iron wire in good condition has increased of late years, owing both to the use of inferior metals in manufacture and to the more general presence of corrosive agents in the atmospheres of cities, industrial regions and along steam railroads. The difficulties are increased by the fact that the life of the joints is not equal to the life of the body of the wire. Joints deteriorate rapidly and increase in ohmic resistance. The substitution of copper greatly diminishes the rate of depreciation, because the oxide coating on the surface of copper is protective and arrests further corrosion while it remains intact.

Owing to the fact that the tensile strength of hard-drawn copper does not exceed approximately 65,000 lb. per sq. in., it is not feasible to employ small wires, except in mild climates. The telegraph companies have settled on a standard of No. 9 B. & S., weighing 209 lb. per mile, which has a breaking strength of about 620 lb.

The use of copper clad steel wire in place of this conductor is not economical except where the conductance of No. 9 copper is in excess of the transmission requirements. For example, the use of No. 9 copper for a telegraph line 150 miles long is an economic waste of copper, because a much smaller conductor would provide the necessary conductance. At the same time the correct size of copper from a conductance standpoint would not be strong enough to sustain loads of wind and sleet, and would not give reliable service—if in fact it would stay up at all.

Such a case forms an ideal illustration of the value of copper clad steel wire, whose tensile strength is approximately 90,000 to 100,000 lb. per square inch. This type of wire could be substituted for solid copper, in this instance, with considerable saving in cost, because its superior tensile strength permits the use of smaller sizes than are permissible with copper.

Of course the substitution of copper clad steel for copper, where the size of copper needed electrically is also sufficiently strong mechanically, is out of the question. Had my statement that copper clad steel is an economical and suitable telegraph conductor been unaccompanied by the important qualification that 300 miles is the limit on its use in circuits without repeaters, Mr. Gherardi's general objection on the score of low conductivity would be well sustained. But in the light of all the analysis of the problem it seems to be clearly established that the superior strength of copper clad steel wire, taken in conjunction with present market prices, proves it in for distances in simplex service up to about 300 miles.

Digitized by Google

DISCUSSION ON "THE USE OF POWER LIMITING REACTANCES WITH LARGE TURBO-ALTERNATORS," "SOME RECENT TESTS OF OIL CIRCUIT BREAKERS" AND "DEVELOPMENT OF THE MODERN CENTRAL STATION." CHICAGO, JUNE 27, 1911. (SEE PROCEEDINGS FOR JULY, 1911.)

(Subject to final revision for the Transactions).

John W. Lieb, Jr.: Once again we are indebted to Dr. Steinmetz for a splendid and acute analysis of what is essentially a practical problem. With that keenness of discernment which we have been accustomed to expect from Dr. Steinmetz, he has touched upon a number of vital points which are of momentous interest to the present and the future of central station work. In the papers of Messrs. Schuchardt and Schweitzer, and in the paper of Mr. Merriam, we have notable instances of the method of applying scientific research to the investigation and solution of electrical problems, and the Institute is to be felicitated in having before it the details of these tests as affording material for thought.

In Mr. Schuchardt's paper he refers to the points to be determined by the tests which were made, indicating as the first, the instantaneous short circuit current of turbo-generators without external reactance. These questions referred to by Dr. Steinmetz and the other authors are matters which have been given careful consideration by the New York Edison Company, for instance, as another of the companies having these large problems to deal with, and this first element was one of the first questions which presented itself for investigation; and it was found that there was a considerable and wide variation as between types of generators, particularly turbo-generators, in this matter of internal reactance. There were tests made between types of generators as to the amount of internal reactance, amounting to as great a difference as two to one. It has therefore, opened a new light as to the possibility of control within the generator itself of the application of an increased amount, by and within the practical limitations which the applications permits, of internal reactance, and by an increase of internal reactance you make it possible to limit the amount which need be applied externally.

It is difficult to conceive of the tremendous disturbance that takes place on a large interlaced system by short circuits in feeders or failure of generators. With ten, twenty, or thirty substations distributed over vast areas, having hundreds of synchronous machines working in parallel, the disturbance and throwing out of synchronism of this vast number of units, and the enormous difficulties involved in starting up these different substations widely separated, present unique problems, and it is therefore well worth most careful consideration to reduce the possibilities and the effects which these enormous concentrations of power in local disturbances may call forth.

The concentration of power for economical reasons in these huge power plants, the dependence for vast industrial enter-

Digitized by Google

prises and for our transportation systems, as well as for lighting and industrial power, make it absolutely essential that they shall be protected against disturbance, and that every possible precaution should be taken, which experience or ingenuity can provide, against irregularity in operation, because if these huge systems are going to be subjected to disturbance and interruption of service, we shall have reached a point where something radical will have to be done; but very fortunately with these elements which are brought before us, and other elements which are not here referred to, we can feel sure that the future provides fairly safe guarantees against interruption of service which produce very serious results in a community served by these vast enterprises. I am sure that we are very much indebted to the gentlemen of the Commonwealth Edison Company for having laid before us in great detail the results of their tests and experiments, with a view to arriving at a satisfactory solution of these problems, and to Dr. Steinmetz for having put his finger on the essentially important elements which are such prime factors in the development of the modern central station industry.

M. H. Collbohm: Mr. Merriam has presented us with very valuable data on the operation of oil switches designed for severe service conditions which data have been obtained from actual tests.

I note, however, that all these tests have been made on an oil switch type employing the vertical break. It would have been very instructive if the test had also been made on a switch of the horizontal break type in order to allow comparison between these different constructions.

It seems to me that the horizontal break oil switch would offer greater prospects for successful operation under severe conditions for the following reasons:

1. The break occurs in the lower part of the tank with a considerable head of oil above the break, in contradistinction from the vertical break where the arc starts nearer to the surface of the oil. This seems to be of great importance considering that the arc is most vicious at the moment of separation of the contacts when the current has its greatest value.

2. The horizontal movement of the thin switch blade through the oil combined with the tendency of the arc to rise vertically causes this arc to continually come into contact with fresh and cool oil layers thus extinguishing the arc sooner than would be possible in the vertical break switch where the arc tends to maintain its original vertical position. The break in the vertical type must therefore be considerably longer thus rendering this type of oil switch materially more expensive for the same rupturing capacity.

3. The knife blade form of contact pieces insure a more positive contact in the clips than can be obtained by the wedge or butt contacts usually employed in the vertical break switch for higher voltages.

Digitized by Google

The speaker has had experience with both types of switches on high tension lines and feels it his duty to express his satisfaction with the cheaper horizontal break oil switch which has opened without trouble several short circuits without the dampening influence of reactive coils.

The main advantage claimed for the vertical break type, *viz.*, the opening by gravity does not seem to the speaker to be superior to the opening by springs. The latter can be adjusted for a more rapid operation thus increasing the effectiveness of the switch. The gravity break type in the speakers experience in one instance failed to establish good contact in closing resulting in the partial burn off of the contact clips and carbonizing the oil.

In regard to the rupturing capacity of the oil switch in general I would like to be informed what the considerations are for giving the same switch type a higher rating on lower voltage than on higher voltage, as given by some manufacturers, catalogues. Ordinarily one would expect greater damage to the switch at lower voltage due to the greater $I^2 R$ energy in the rupturing arc. The speaker in laying out the switchboard for a 16,000-kw. hydroelectric station interconnected with others of still higher rating, suggested the use of a high generator voltage in order to lessen the possibility of trouble to oil switches under short circuit conditions but was informed by the switch manufacturer that the standard voltage of 2,300 volts would be preferable.

As the speaker at that time could not get a satisfactory explanation for this advocating a lower voltage he would appreciate very much to learn at this time the reason for this method of rating oil switches.

Dr. Steinmetz in his paper has given a very interesting exposition of the development of the present alternating current central station from the old direct current plant with particular reference to the external reactance coil as one of the characteristic protective features of the modern large sized plant. The development of this protective device was brought about by the desire to overcome the danger from the enormous short circuit current in the system, particularly in a plant with synchronous turbo-generators.

The question arises in my mind whether this heavy short circuit current could not be materially reduced by other means, possibly in addition to the proposed choke coil. The present practice of sacrificing regulation in the synchronous machines in order to reduce the short circuit current, is only a small help, and it seems that the liberal use of induction generators with their characteristic low short circuit current would aid very materially in bringing about the desired result, both as regards reduction in short circuit current as also absence of necessity for running synchronized.

This type of machinery has already been successfully installed in combination with low pressure steam turbines, and it seems

Digitized by Google

that the equipment of a whole station with induction generators specially designed for a small magnetizing current in connection with synchronous motors floating idle on the system for furnishing this magnetizing current would make a feasible arrangement. The synchronous motor in such installations would have the appearance of an unproductive piece of apparatus, but for the advantage it offers by rendering the respective plant independent from any other synchronous station, its use appears justified. It might thus be considered to be in a same class with the frequency changer.

In such a system the throwing together of stations slightly out of phase may not cause nearly as heavy a shock as if both stations were equipped with synchronous machines only. The last problem stated by the author at the end of his paper, *viz.*, synchronous operation of different stations would then also find its solution.

Aside from city steam stations this induction generator type would also be of considerable advantage in a system of interconnected hydroelectric plants where it could be installed at stations of secondary importance, furnishing power only and leaving the regulation of the system to a synchronous generating station. The installation of a synchronous motor in connection with the induction generators would again render this secondary plant independent from the main station as regards regulation. Such a plant could always be run at highest efficiency, possibly without the use of hydraulic governors and could utilize the total stream flow at nearly all times without the expensive provision of a storage reservoir.

Aside from the development of the reactive coil as a protective feature of a high capacity low tension steam station there have been made developments on other protective devices serving a different purpose in stations of high voltage character, and which may perhaps properly be mentioned in discussing station development:

The aluminum arrester, although it has failed several times in the speakers experience to perform its function without being destroyed itself by mere internal disturbances in the system, represents nevertheless a considerable improvement over the older types.

In addition to the use of this arrester the speaker has advocated and put into successful operation a scheme of additional protection to station apparatus consisting in the use of solid non-coated iron wire of high permeability for station wiring, extending from the high tension transformer taps to the point where the arrester connections tap on the transmission line, which should preferably extend to the first tower outside the power house. The advantage of this scheme lies in the greatly increased ohmic resistance which the iron wire, due to the skin effect, offers to any high frequency surge such as lightning. The choke coil in particular, representing quite a length in the con-

Digitized by Google

ductor, should be of soft Swedish iron. This scheme of using iron wire choke coils appears also to get into favor in Europe judging from a bulletin of a responsible European manufacturer of such coils recently received by the speaker.

The usual danger from high voltage building up on the reactance of the series transformer by any high frequency disturbance has been overcome by an arrangement of the speaker of shunting a small electrolytic cell across the high tension terminals of the series transformer.

Inasmuch as the skin effect of the iron wire was sought as an additional choking effect for protecting station apparatus, it had on the other hand to be removed from the path of the lightning discharge, particularly the overhead ground wire on the transmission lines was investigated by the speaker in 1909 with the result of recommending copper clad steel for ground wire purposes instead of steel which had been used exclusively before. Subsequent high frequency tests made at the University of Wisconsin on iron and copper wires have proven the speakers arguments in favor of copper.

All the before mentioned schemes for additional protection to station apparatus have been tried out on one of the hydroelectric transmission plants built by the speaker and have worked out to entire satisfaction. This particular plant (of the Northern Hydroelectric Power Co. at High Falls, Wis.) has experienced many severe lightning storms which caused the arresters to act very frequently but there has never been the slightest damage to any of the apparatus.

A further development in lightning arresters has recently been made in Europe where a number of prominent central stations have been equipped with arresters consisting of one or more banks of condenser elements shunted by a grounding choke coil. The condenser battery acting on high frequency disturbances of any voltage, even of a very low value to which the electrolytic arrester would not respond, while the choke coil takes care of accumulated static. This arrester is reported to have given excellent results.

There are some minor details which have recently undergone development and which when taken as a whole may exert a marked beneficial influence upon the safety of central station operation.

The instrument and control panels in a large station become so numerous as to be difficult to oversee, and a reduction in their number and a clear distinction between the various instruments and panels becomes very desirable. The voltmeter and ammeter for the generators may be omitted from the respective panels and one instrument of each kind placed on a swinging bracket to serve for all the various machines by providing a receptacle and plug for each of the respective panels. A wattmeter and power factor indicator is generally sufficient for the control of the generators. If curve drawing instruments are

Digitized by Google

used they may serve at same time as indicating instruments thereby rendering this latter instrument superfluous. A duplicate transmission line may be equipped with one wattmeter only by paralleling the secondaries of the respective current transformers.

The panels and the instruments should preferably be black and the instruments have their designation printed in bold types upon their scales, such as "Volts—Amperes—Watts, etc.," the graduation of the scales should be in decimals to facilitate reading. Only instruments with flat glass covers should be used to avoid the disturbing effect on the curved glass covers of the usual horizontal edgewise instruments. The illumination for the board should be accomplished by diffused light from well above the board in order to have no reflex whatever from the instruments.

The individual panels should be marked by genuine enameled name plates which do not oxidize or fade as in the case of the usual copper or paper name plate. Each circuit or group of circuits should be provided with a blue signal lamp above the board to operate in conjunction with the alarm bell in order to indicate immediately the circuit in trouble.

The above precautions may appear insignificant to the designer but they are of real value to the operator and consequently to station safety.

Besides in the Central station proper there have also been made developments in other parts of the system notably the transmission line. I wish to mention only the flexible type of transmission tower and quite recently the appearance of the composite transmission cable consisting of aluminum or copper strands and a steel center of very high elastic limit. By this arrangement the elastic limit of the composite cable is considerably increased, allowing of a wider spacing of towers with consequent reduction of cost in line construction.

D. B. Rushmore: In the President's Address this morning and in the papers which have been presented, we have the problem of disturbance from increasing magnitude—a problem most universal in the present age in social, political, industrial and engineering life. In designing for any particular condition, a design is made to meet the major point under consideration. We design machines, power plants and power transmission systems for operation, but a compromise must always be effected in considering the factors involved when we take into consideration the emergency conditions.

In the discussion that we have had on these conditions of central station operation are involved one example of a change taking place in power transmission systems, and in what are becoming very large stations for industrial power use. The magnitude of individual pieces of apparatus is increasing, the magnitude of stations, and of systems, and very largely of a number of stations tied together. While in so many of our old

Digitized by Google

problems the boy, as it were, has been relatively harmless, the young man as he appears now, older, larger, stronger, and more powerful is becoming a more disturbing factor, and we have yet to look ahead to the full grown man, to the power systems that are going to cover very much larger areas than at present, and be of very much larger capacity.

In designing apparatus for these conditions a compromise is necessarily effected, and the illustration we have had of placing reactance outside of the machines, allows in many cases a better machine to be designed. While the machine has to be designed for operation, occasionally the best of machines have to be repaired, and to place a large internal reactance in machines involving high, true self induction means, as a rule, increased difficulties in repairing machines.

To bring before the Institute one problem as yet unsolved, we have had for years in hand the development of an automatic resistance which will protect the circuit against high voltage. This has been done in the aluminum lightning arrester, which in itself essentially is an automatic resistance varying with the voltage. What we need now is an automatic reactance varying with the current, something not yet obtained, and something which is well worthy of the best study of inventors. I think that such a thing is possible, as well as likely. It has not yet been developed with sufficient rapidity to handle the problem of these large instantaneous short circuits. We must also consider that any change in condition is to be met with other changes and in connection with systems possessing large capacity or induction, all additional reactance brings with it certain possibilities which ought to demand a very much larger use of protective apparatus.

C. W. Stone: Last year at a meeting the point was raised in regard to the ultimate capacity of oil switches. In the paper by Mr. Cheney of Philadelphia, there was some question raised about the ultimate capacity of oil switches, and the suggestion was made that it was possible that we would need a new type of switch in order to handle these large capacities. I think the paper by Messrs. Schuchardt and Schweitzer demonstrates that by the use of reactances and the use of the larger 10 in. oil pot switches we do not need a complete redesign of the switches. The switches are large enough even to handle such systems as the Commonwealth Edison Company, and instead of being limited by the switch, it is perfectly possible to still increase the ultimate capacities of our stations.

Before I stop, there is one thing I think I should bring out, and that is I think we owe a very great debt of gratitude to the officials and engineering organization of the Commonwealth Edison Company for the very thorough way in which they have carried out these tests. There are very few places in the country where such a complete and fundamental investigation of the shocks to systems under short circuit could be made as thor-

Digitized by Google

oughly as they were made by the engineers of the Commonwealth Edison Company in Chicago, and I think that the whole engineering profession should feel a debt of gratitude for this paper by Messrs. Schuchardt and Schweitzer, reporting on these tests.

Mr. Merriam in his paper points out that with the 10-in. oil pot the strains or pressures are reduced to about one-third or one-fifth of what they were with the 8-in. pot. I think that is a fundamental point. One of the previous speakers mentioned the possibility of using a horizontal break. I think he lost sight of one of the fundamental principles which has been employed so generally in the type of switches described in the paper and that is by using the vertical break, it is possible to so adjust the baffles in the switch as to confine the pressures arround the arc, and thus extinguish it more readily. This is difficult to do in a horizontal break type of switch. I think if the engineers here give this matter attention, they will be convinced that the vertical break, with the type of baffling usually employed, has greater possibilities for large capacities than any other type yet proposed.

There is another point. Mr. Merriam in his paper refers to the small amount of oil which is thrown out after repeated short circuit. I think many engineers in witnessing some of these tests would have said that the amount of oil thrown out was excessive. Complete tests were made to find out how much oil could be thrown out, and the switches were opened under short circuits time after time, without changing the oil, and then the amount that had been thrown out was measured and it was found that only about five per cent had been thrown out. To be sure, it is not a dangerous amount, and yet it does demonstrate that it is adv sable to install these switches in fire-proof compartments, such as brick, concrete or soapstone.

Mr. Lieb brought out the point about the possibility of the increase in the internal reactances in the generators. It is perfectly possible to design generators with higher internal reactance, but you will always sacrifice something.

I do not think that a generator with twice the internal reactance of the present machines, such as those under test, would have as big a factor of safety as the generators which are now in operation. I think also the point should be brought out that the high internal reactance generators will not accomplish what the generator with the external reactance will accomplish, and that is this—with the external reactance, in case of damage to the generator, due to the breakdown of some coil, the amount of short circuit current which can flow into the generator is limited by the reactance which is in series with it. If the generators were built for high internal reactance, and external reactance not used, the effect of the internal reactances on the generator which was damaged would be entirely eliminated, and the amount of short circuit current which could flow into that generator at that time would only be limited by the internal reactance of the other machines operating in parallel.

Digitized by Google

I think, therefore, what we should aim to do is to make the generators as safe as possible, and then protect them and the system and the oil switches by means of the external reactances.

I think another very interesting point brought out by Messrs. Schuchardt and Schweitzer is that after repeating short circuits, nearly 150 of them, there was absolutely no damage to the generators, no displacement of the coils, no displacement of the field structure or the shafting of the machine. I think that demonstrates the desirability of the reactance about as well as any point that has as yet been brought up.

B. G. Lamme: Two of the papers presented this morning have brought out the fact that reactances are advisable in the protection of large capacity alternating current generators. I fully agree with the authors of the papers on this point and have held a similar opinion for several years. Experience shows that, in commercial operation, sooner or later short circuits will occur on all generating systems, especially if they are of high voltage; and if the machines are of very large capacity the stresses exerted by the short circuit current will be so great that there must be some means provided for limiting the maximum current.

An interesting point to me in the paper by Messrs. Schuchardt and Schweitzer is the amount of reactance which they found advisable. From their tests they found that a reactance which limited the maximum current to 14 times normal was satisfactory. That is an interesting figure, for it is the one which we had reached as the limit, in our experience with large generators. We found that when we could keep the current down to 12 or 14 times normal current on dead short circuit there was very little, if any, difficulty in bracing the end windings to stand the shock. We also found that, in a great many cases, there was no difficulty in getting that amount of reactance in the machine itself without making an abnormal design.

However, that question depends somewhat on other features than on the construction of the winding itself. The speed comes in as an important condition. For instance, if you have a moderate speed turbo generator of large capacity it may require an abnormal design to obtain a high reactance inside the machine itself. If you double the speed, and thus cut the number of poles in half, you may find it difficult to obtain a low reactance in the machine. As the speed is increased and the number of poles is decreased the reactance naturally tends to increase and if the speed is made sufficiently high the machine can have sufficient reactance in itself to limit the short circuit current to a satisfactory value. That being the case, no external reactances will be required in such machines. For example, if a 10,000 to 15,000 kw., 25 cycle machine is made with two poles, 1,500 rev. per min., the internal reactance would naturally be very high. Also, if the same capacity machine for 60 cycles has four poles and operates at 1,800 revolutions, a fairly high internal reactance can readily be obtained. My experience with such

Digitized by Google

machines has been that there is little or no occasion for adding reactances outside the machine.

Furthermore, in these high speed machines it does not appear to complicate the machine, or increase its cost, to obtain sufficient internal reactance. In such machines a comparatively small number of coils of large size will naturally be used and such construction tends at once toward high reactance.

One fact, which should be considered in the use of reactance, is that the higher the reactance in circuit the higher the machine will be worked for a given terminal voltage, or the lower the terminal voltage with a given generated e.m.f. In other words, the addition of reactance in the circuit directly tends to decrease the available output of the machine.

On the other hand, the conditions which tend toward increased output in the machine itself also tend toward increased internal reactance, relatively, and it may be assumed that, if the machine is constructed for high internal reactance, in many cases it can also be constructed for very high output. This interrelation of high internal reactance and high output can be illustrated in a rather simple manner. Assume, for example, that with a given number of armature slots, the ampere turns per slot can be doubled, by changing the proportions of the slots, and by various other arrangements. It is obvious that the reactance of the machine as a whole would either be increased slightly, or at least, would not be decreased. However, the output would be very materially increased and in consequence the maximum short circuit current on the machine would either be decreased or would be no greater than before, while the normal current would be increased. In consequence, the machine with increased output would have no worse short circuit conditions than before, or the conditions might even be materially improved due to increased reactance. The problem therefore turns purely upon questions of design, such as obtaining high ampere turns per slot, while at the same time avoiding excessive eddy current losses and heating in the slot conductors. Greater refinements in the proportioning of the windings are now being carried out than were thought necessary only a few years ago.

For parallelling large alternating current systems, low reactance is not a necessary condition, but relatively low resistance is required. Experience has shown that there is a certain limiting resistance which can be used, above which instability of operation will occur. The limiting value of that resistance is, to a certain extent, a function of the construction of the machines themselves. For instance, if the synchronous machines have large cage dampers on their fields, the resistance between the machines can be higher than with undamped machines. In some tests made a few years ago it was found that with an ohmic drop corresponding to 20 per cent of the terminal voltage of the machine, instability was reached with the very best damper which could be put on the field. With less damping action

Digitized by Google

a lower resistance produced instability. If, therefore, a 25 per cent to 50 per cent overload condition is to be considered, then at normal load, only from 10 per cent to 12 per cent ohmic drop is permissible between the machines.

At the same time that the above tests were made for limiting resistance drop it was found that a very high reactance could be used between the machines without producing instability. The tests showed that the amount of reactance permissible was far greater than that required to limit the maximum current to a safe value in case of short circuit.

There is one point not brought out in Mr. Schuchardt's paper and that is that the damage to the winding is not merely a function of the maximum current but is also dependent upon the duration of the short circuit and also upon the number of short circuits which may occur. In connection with the New Haven Railway generators, where we had to add reactances to reduce the shocks on the machines and system, it was found that an individual short circuit apparently produced but little damage to the armature windings, but in the preliminary operation of the system, as many as 25 to 30 short circuits occurred per day, and, even with such frequent short circuits, the winding was found to stand up for months before a breakdown would occur. Also, as these machines were equipped with very heavy dampers the maximum short circuit current would hold up to practically highest value for 25 to 30 alternations, which was found to be a much more severe condition than where the short circuit was of much briefer duration. The results indicated that it was the continued hammering of the insulation by the short circuit stresses which did the most damage, and not the individual shock.

A remedy applied for this condition on these machines was the use of reactances in the circuits from the machines. These were of the iron-core type and have proven very effective. At normal load the iron is worked at such a low induction that the maximum current on short circuit will just about saturate the core. When so proportioned, an iron reactance is apparently as effective as an air-core reactance and has very little external stray field. I will say, however, that in constructing this reactance a large internal air gap is allowed—about 5 in., so that it is, to a certain extent, an air-core reactance with an iron enclosing circuit.

In these New Haven machines it was found that a reactance allowing 15 times normal current was not sufficient to protect the machines, and it was necessary to put in reactances sufficient to reduce the current to seven or eight times normal. However, the conditions were abnormal, as the output of the machines was single-phase current which required heavy cage dampers on the rotor fields in order to suppress the magnetic pulsations due to the single-phase armature reaction. With these heavy dampers the short circuit conditions were very much worse

Digitized by Google

than those encountered in ordinary generators of the same capacity. Experience with other types of machines has indicated that if sufficient reactance is supplied either internally or externally, to limit the current to about 12 times normal, it will protect the usual types of machines.

W. L. Waters: The tests made at the Commonwealth Edison Co., and the system of protection there worked out, are similar to those carried out three years ago by the Westinghouse Company, in connection with the Cos Cob Power Station of the New York, New Haven and Hartford R.R. Co. At the time the single phase equipment was being installed, this power house was subjected to a continuous series of short circuits, due mainly to the non-selective action of the circuit breakers; these short circuits sometimes occurring as frequently as 25 or 30 per day, and varying in intensity from a dead short circuit to one at the

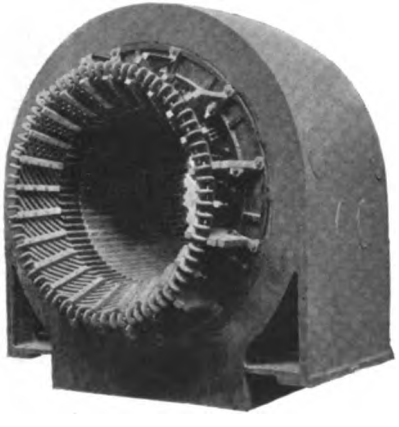


FIG. 1

end of a line having 5 per cent resistance drop. The system of protection worked out for that power station was:—an improved system of armature coil bracing on the turbo generators; the connection of a 9 per cent iron cored choke coil permanently in series with the line; and series or relayed oil switches, which in cases of short circuit introduced resistance into the line, thus decreasing the magnitude of the short-circuit current and raising its power factor before finally opening the circuit. This selective circuit breaker action and somewhat elaborate system of protection was installed on account of the exceptionally severe conditions of operation, and it is probable that some less complete arrangement such as that employed by the Commonwealth Edison will afford ample protection for the average power station.

The system of armature coil bracing for the turbo generators is shown in the accompanying illustration Fig. 1. It will be

Digitized by Google

seen that it consists of heavy wood blocks clamping the winding to metal brackets by means of insulated bolts. This bracing can be made as rigid as desired, and has the advantage of being permanent, as it does not deteriorate with time like the rope or twine lashing sometimes used. Numerous tests have been made on generators equipped with this system of bracing, by short circuiting when excited to 30 per cent above normal voltage, and in no case has any movement of the coils been noted. In fact the shock of the short circuit seems to be felt more on the frame of the generator than on the winding.

The Westinghouse tests above referred to, which were oscillograph records made to determine the effect, on the generator short circuit current, of including various types of self induction in the circuit, were made in 1908 on 2,000 kw.; 500 kw. and 300 kw. generators, tests being made at 60 and 25 cycles, both with and without dampers on the field magnets. The majority of the tests were made single-phase as it was found impossible to obtain consistent results on three-phase tests because of variation in the time of closing for the short circuiting switches in the three phases. The results of tests checked up well with theoretical calculations; the actual shape of the short current waves being found to be dependent on the power factor of the short circuit and the phase of the current at the instant the short circuit was closed. Under the worst conditions, the current wave immediately after closing the short circuit lay entirely on one side of the zero line, and the maximum peak had a value double that figured by dividing the e.m.f. of the generator by the impedance in circuit. Under the most favorable conditions, the current wave was at all times symmetrical with regard to the zero line, and the maximum peak was approximately the same as the value obtained by dividing the e.m.f. by the generator by the impedance in circuit.

Referring to the relative advantages of auto-transformers, iron choke coils, and air choke coils, for installation in a power station to protect against lightning, surges, and short circuits, it would seem that they all have both advantages and disadvantages; provided in all cases any iron cores used are worked at a sufficiently low magnetic density, so that they do not become saturated at the maximum peak of the short circuit current. An auto transformer, if built with a sufficiently high leakage reactance will undoubtedly afford protection, but it is expensive and is a constant source of loss. A 12,000-kw., three-phase, 25-cycle 4,500 to 9,000-volt auto-transformer will have a full load efficiency of about 99.25 per cent, while the efficiency of a 12,000 kw. 9,000-volt turbo-generator is practically the same as the corresponding 4,500 volt machine, so that this 0.75 per cent loss in the transformer is not compensated for in anyway. If we assume the generator operates 50 per cent of the time and that energy costs 0.4 cent per kw-hr., this auto transformer results in an annual loss of $1,570 which capitalized at 8 per cent represents $20,000.

Digitized by Google

In regard to the relative desirability of air and iron choke coils:—an air choke coil is appreciably cheaper in first cost, but possesses the disadvantage of a strong external magnetic leakage field which is liable to effect the instruments and to produce mechanical stresses or heating in surrounding objects. It has also been found from experiment that an iron choke coil is less liable in a short circuit to produce the distorted current wave located entirely on one side of the zero line which was above referred to. So that as a result of this it would seem that an iron choke coil, provided there is no saturation at the high current values attained on short circuit, is somewhat more effective in reducing the maximum current on short circuit than would be an air choke coil having the same impedance for steady values.

John J. Frank: In the discussion of the papers by Mr. Merriam and the paper by Mr. Schuchardt and Mr. Schweitzer I will endeavor to confine my remarks to that of the designing engineer, on the current limiting reactance which forms such an important part of both papers.

Neither paper, I believe, intends to convey the impression that every distributing system great or small should be provided with a current limiting reactance as a positive insurance to the elimination of all the troubles experienced by the operating engineer.

Where the impedance of the generator and the transformers is small the introduction of a current limiting reactance will no doubt, relieve the system to a great extent of both mechanical and electrical strains. This is supported not only by the papers presented but by the experience of the Consolidated Gas & Electric Co., of Baltimore, who installed a reactance for the protection of a 5,000-kw., 13,200-volt 25-cycle turbo generator. The particular causes of excessive current are short circuits between the lines, bus bars and generator leads, and grounds on Y connected systems with grounded neutral. The possible effects in mechanical strains upon connected apparatus can best be understood by reference to the strains in a transformer.

Take for illustration a 5,000 kw., three-phase transformer, having delta connected primaries supplied with 9,000 volts, 25 cycles. The normal current in the windings is 185 amperes; the measured reactance of the windings is 2.3 per cent. With the secondary windings short-circuited and constant terminal voltage impressed upon the primary windings, the current flowing in the latter would be $\frac{185}{0.023} = 8050$ amperes. The distance between their magnetic centers is 1.7 in. = 4.32 cm.

The mechanical work of the magnetic forces of a circuit in which current is flowing is

$$W = \frac{I^2 L}{2} \qquad (1)$$

Digitized by Google

Where I is the measure of the current and L the inductance of the circuit. This quantity is analogous to the energy of a static charge, $\frac{C E^2}{2}$, and to the energy of motion, $\frac{M V^2}{2}$.

If F is the force in grams produced between primary and secondary windings, and l the distance between their magnetic centers, the mechanical work done in moving one set of coils through the distance l against the force F would be

$$W = F \times l \text{ g.-cm.} \tag{2}$$
$$= F \times g \times l \times 10^7 \text{ joules.}$$

Hence, substituting (1) and (2)

$$Fl = \frac{I^2 L}{2g} 10^7 \text{ g.-cm.} \tag{3}$$

and

$$*F = \frac{i^2 L}{2 g l} 10^7 \text{ g.} \tag{4}$$

which is the mechanical force existing between the primary and secondary windings of a transformer at the short-circuit current i.

At short-circuit, the total supply voltage e is consumed by the leakage inductance of the transformer, therefore:

$$e = 2 \pi f L i \tag{5}$$

Hence, substituting (5) in (4) gives

$$F = \frac{e i 10^7}{4 \pi f g l} \text{ g.}$$

$$= \frac{812 e i}{f l} \text{ g.} \tag{6}$$

Inserting the values of e, i, f and l in (6) we have,

$$F = 545 \times 10^6 \text{ g.}$$
$$= 1{,}200{,}000 \text{ lb.}$$
$$= 535 \text{ tons.}$$

This force is exerted between the six faces of the three primary coils and the corresponding faces of the secondary coils; and thus on every coil there is exerted the force

$$\frac{F}{6} = 89 \text{ tons.}$$

Digitized by Google

This is the average force, which varies between 0 and 178 tons, and thus reaches an enormous value.

If we denote the leakage reactance of a transformer by x, substituting $i=\frac{e}{x}$ in (6) gives as the short circuit force at maintained terminal voltage e, the value

$$F=\frac{e^2\,10^7}{4\,\pi\,f\,\varrho\,l\,x}=\frac{f\,l\,x}{812\,e^2}\ \text{g.}$$

That is, the short circuit stresses are inversely proportional to the leakage reactance of the transformer. It follows, therefore that on systems of very large powers safety requires the use of high reactance.

In order that a reactance shall protect, its voltage characteristic should be a straight line; that is, it should be proportional to the current flowing. The following empirical formula has been followed in the design of such coils.

The voltage induced in a coil in a magnetic field is

$$E=\frac{4.44\,\phi\,f\,T}{10^8} \tag{7}$$

in which ϕ is the flux enclosed by the conductor, f the frequency in cycles per second, and T the number of turns. The flux produced by a solenoid or coil without an iron core is

$$\phi=\frac{I\,T\,d}{K} \tag{8}$$

in which I is the current in the coil, T the number of turns, d the inside diameter, and K an empirical constant which equals

$$K=0.125+0.28-\frac{L}{D} \tag{8a}$$

where (see Fig. 2) L is the length and D the mean diameter of the solenoid. Substituting (8) in (7)

$$E=\frac{4.44\,I\,T^2\,d\,f}{K}\,10^8 \tag{9}$$

and

$$T=4750\,\sqrt{\frac{K\,E}{I\,d\,f}} \tag{10}$$

Digitized by Google

The latest expression of the designer is shown in the accompanying illustrations Figs. 1 and 2. The core consists of a cylinder of concrete in which are imbedded anchor plates for clamping bolts.

Radial strips of wood treated to give greatest possible insulation are attached to the core and are provided with grooves into which the conductor is wound. The conductor consists of bare stranded cable and is wound in one continuous piece as shown in the photograph so that eddy currents which might heat the solder or brazed joint in the center of the winding is eliminated. The end turns are given increased space over the average allow-

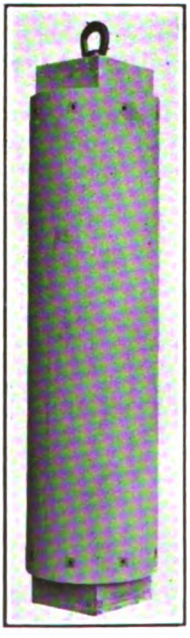


FIG. 1

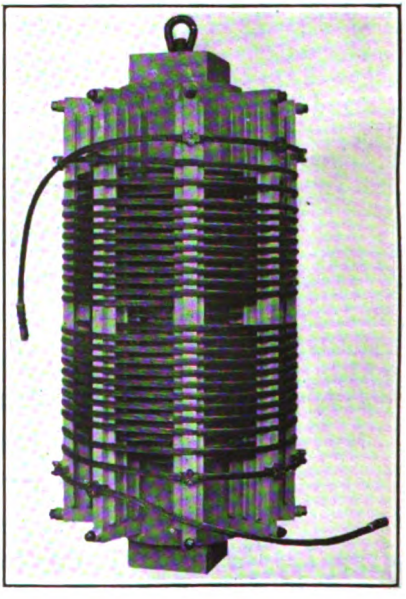


FIG. 2

ance to afford better reliability against electrical or magnetic shocks to which it may be subjected. In addition the conductor on the last turn at each radial support is clamped to further increase the rigidity of the coil. That the reactance operated satisfactorily in the tests made is brought out in the two papers. In order to facilitate cleaning and inspection, the cores and wooden radial supports are given a coat of cream color enamel paint. All of the bolts, nuts, and clamping members are made of brass rather than steel, to eliminate any heating due to the concentration of the flux which would be induced by a magnetic material.

Digitized by Google

Louis A. Ferguson: I would like to know whether Mr. Lamme desired to convey the impression that it would be better to use machines of high reactance rather than external reactance? My reason for asking that question is because he made the statement, if I heard him correctly, that by using machines of high reactance you could increase the output, by using a large number of coils per slot.

Our experience here in Chicago has been rather the other way; that is, we have found with our earlier large machines that there was considerable heating, and that the output for the capacity of the machine was limited, and it was necessary, in order to obtain the desired output, to reduce the number of coils per slot, and for this reason, because of the two statements going together, I would like to have him state whether in his opinion it is better to use machines of high reactance, or machines of low reactance, and external reactance connected therewith.

In replying to the question I would suggest that Mr. Lamme confine his remarks to the large machines, such as the 12,000 to 20,000-kw. and leave out of consideration the small machines of say, 1,000 to 2,000 kw.

B. G. Lamme: In machines of large capacity, such as turbo-generators, it is advisable and practicable to obtain large internal reactance by suitable design. If you can increase the number of ampere turns per slot you will tend to increase both the output and the reactance of the machine, and therefore the percentage of current on short circuit will be relatively decreased. In practice it will be found that high reactance machines are generally of relatively high output for given dimensions.

As to the matter of increasing the number of ampere turns per slot, that is a question of design principally. The difficulty with high ampere turns per slot is principally from eddy currents due to local flux conditions in the slot. Very much can be gained on this point by careful design and there is evidence that we can go much further in this regard than we have yet gone.

I think the whole tendency in turbo-generator design is toward the largest number of ampere turns which can be gotten into the armature, without increasing the dimensions, and such increase in ampere turns will also be accompanied by increase in reactance. I am in favor of putting as much reactance as possible into the machine itself up to the limiting amount required, and whenever a sufficient amount for protection cannot be put into the machine itself, then put the remainder outside. I do not favor making the internal reactance as low as possible and putting high reactances outside for I believe that this is a relatively expensive method of procedure.

R. B. Williamson: This paper has demonstrated very clearly the desirability of a certain amount of reactance in connection with large turbo-generators. This reactance may be external as in the present case, or it may be in the machine itself, provided

Digitized by Google

the design is such that a high reactance winding can be used without making a less desirable design in other respects. High reactance in the generator itself means a high specific loading for the stator (*i.e.*, high value of the number of ampere-conductors per slot or per inch of periphery.) In large turbo-generators, most of the heat liberated in the stator copper must pass through the insulation and into the stator iron before it can be carried off, *i.e.*, the cooling effect of the ends of the coils is comparatively slight. In order, therefore, to limit the internal heating of the stator coils, an increase in the number of conductors per slot must be accompanied by other changes in the design, in order to limit this heating. This is particularly true in high voltage generators where the heat has to pass through a considerable thickness of insulation.

Since it is clearly desirable to have a certain amount of reactance in order to avoid the disastrous effects of short circuits on large units, and, since a high reactance involves poor inherent regulation, it follows that close inherent regulation should not be specified for such units. Moreover, it is now general practice to take care of the voltage regulation by means of automatic regulators, so that there is no great necessity for close inherent regulation.

Another point to be considered is that, other things being equal, high speed machines are more likely to be damaged by heavy short circuits than low speed ones. The internal reactance of the high speed generator will usually be less than that of the lower speed machine, but even assuming the same reactance in each case, the coils in a high speed generator span a greater angle, hence the projecting ends of coils are correspondingly longer and more difficult to support securely.

Clarence P. Fowler: In addition to the superior features mentioned, by Dr. Steinmetz, of direct current as compared with alternating current for supplying electrical energy to the congested portions of our larger cities, the following inherent advantages of the former system for this class of service, have been doubtless, in no small measure, responsible for the persistence of this system, (through the use of alternating current-direct current conversion apparatus) to the exclusion of alternating current supply:

a. With direct current available, special devices are unnecessary for charging small storage batteries, such as used in automobiles, etc.

b. As most isolated plants for office buildings, etc., are of the direct current type, the use of direct current distribution at once facilitates, the installation of breakdown service connections for such plants.

c. With alternating current distribution there is considerably more high tension feeder copper required per maximum kw. than with the alternating current-direct current system and as high tension cables cost vastly more per lb. of copper than low tension

Digitized by Google

cables, it is evident that there will be quite a marked saving in this direction in favor of direct current distribution.

d. There is also quite a difference in favor of the maintenance of low-tension cables as compared with high-tension cables and even assuming equal life for each, the scrap value, at the time of removal, would be perhaps 35 per cent to 50 per cent lower for high tension than for low tension cables.

The analogy drawn between the necessity for the use of reactance in connection with our modern high voltage, high-power systems, on the one hand and the resistance of lines, feeders and mains of the older and smaller direct current systems, on the other, is interesting.

The use of reactance, as an adjunct to the operation of synchronous apparatus, as a means of affecting voltage regulation has been fully appreciated, for some time past. In 1905 the writer discussed, the possibilities of the use of reactance, for this purpose, and showed by means of waves, giving the relative phase relations of e.m.f. and current, that the inductive voltage, across a reactance, could be made additive to or subtractive from the delivered line voltage, depending upon the intensity of field charge of the connected synchronous apparatus.

It is, however, only comparatively recently that the power-limiting capabilities of reactances have come to the fore. This, no doubt, has been largely due to the marked movement toward consolidation and concentration, in the central station industry, resulting in unified systems of gigantic proportions, the loads upon which may fluctuate suddenly through a wide range or still worse, short circuits on such high-powered systems may give rise to rushes of current, the volume of which was hitherto unknown, in previous systems. The change that has taken place in the size of central stations will be apparent, when it is noted that the U. S. Department of Commerce and Labor, reports that the average size of central station grew about 72 per cent, in the five year period from 1902 to 1907.

The violent forces acting upon generating transforming and switching equipment resulting from short circuits, on high-powered systems, have, in many instances, manifested themselves in no uncertain way, in the complete destruction of the switching equipment and oftentimes with considerable damage to generating and transforming equipment, in the absence of power-limiting reactances. With the practical elimination of the reciprocating engine from these large stations and the substitution therefor of the steam turbine, a type of apparatus has been introduced the construction of which is peculiarly susceptible to mechanical strains, due to sudden surges of current of large volume. This condition in the turbine, results from the comparatively few poles employed and the consequent relatively greater throw of armature coils, and resulting lack of rigidity of the armature conducting structure. To add to the rigidity of the armature coils, various forms of coil supports, brackets,

Digitized by Google

etc., have been devised, and while this method of construction has greatly aided in preventing distortion of the armature winding, it is evident the method of removing the cause of the trouble through use of properly designed reactances offers one of the most satisfactory solutions of this problem. In fact, one of the largest and most important examples of steam railroad electrification in this country, has found the use of just such reactances a most indispensable aid in the safety and reliability of its power supply apparatus.

P. Junkersfeld: The three papers presented at this session are either based upon or suggested to a large extent by the tests referred to as having been made in the plants of the Commonwealth Edison Company of Chicago. The need for making this long series of tests at considerable risk and expense was brought about by a unique situation. A very large amount of electric power supply business had been obtained and to serve this, there had been installed sixteen (16) large turbo-generators aggregating 204,000 kw. all in a little less than five years. The rapidly increasing responsibility to the consuming public of operating this unusual equipment and the large system of which it forms a part, together with the need of providing additional equipment of still greater capacity and better economy, made it absolutely necessary to make a most thorough experimental investigation and to secure the most positive information on this fundamental feature of reactance in a large system. As a result of these tests the previous tentative plan of installing 6 per cent reactance for each of the remaining thirteen (13) turbo-generators having a frequency of 25-cycles was finally approved and also the plan of installing a limited amount of reactance in each of the two tie lines connecting the Fisk and Quarry Street Stations.

I wish to express appreciation of the careful thought and much extraordinary effort on the part of all the engineers of the manufacturing and operating companies who were in any way connected with these tests, and particularly also to Dr. E. J. Berg and Dr. Chas. P. Steinmetz who gave thereto a very large amount of personal attention.

As a matter of reliability of service, the localization of the effect of breakdowns of whatever nature will probably always be the most important problem. On the one hand there is frequently the temptation to install a still larger amount of protective apparatus which may in itself occasionally cause trouble. On the other hand other methods of securing greater reliability such as independent lines or sources of supply, multiplication of lines, sectionalized operation to a greater or lesser extent, etc., may involve greater expense than is commercially justified.

Referring now to Mr. Lamme's statement, as I understand him, that repeated short circuits do more damage than individual short circuits: In our experience it is the individual short circuit on the high tension system that causes the damage, and

Digitized by Google

which in most cases is so severe that the particular unit or element affected must be repaired or overhauled before it can be again put into service.

At the Annual Convention last year, the discussion of Mr. Cheyney's paper on "Oil Switches" by myself and others indicated a lack of confidence and brought out the fact that very little improvement had been made in oil switches for several years. Tests made during the past year, some of which are included in Mr. Merriam's paper, have indicated the necessity of several improvements in every type and make of oil switches that were tested. They are improvements in oil diverters and baffles, proper reinforcement of various kinds of oil vessels, effect of size of oil vessels, speed of opening, length of break, effect on oil of repeated short circuits and so on. These improvements are in a structural sense of a minor nature, but of much importance in securing more satisfactory and reliable operation of oil switches, and hence I believe we are now justified in placing more confidence in oil switches than before. There is, however, still ample room for further improvements.

It was demonstrated during the Chicago tests that it is not necessary in future that such short circuit tests be made in a large steam turbine driven power house in order to be conclusive as all of the destructive power in such short circuits was found to be due to the stored energy in the generator and none of it to the amount of steam back of the turbine. The tests and investigations described principally in the paper by Messrs. Schuchardt and Schweitzer can, therefore, now be continued in the test rooms of manufacturers as a large generator brought up to speed slowly by a comparatively small motor or prime mover will answer equally as well for further experimentation and at very much less risk and expense.

C. P. Steinmetz: In concluding I wish to say that the oil circuit breaker is one of the most common and most important pieces of apparatus, and at the same time its method of operation is least understood by most engineers, and modifications of it are still continually suggested, based on theoretical considerations, largely erroneous. We must realize that the operation of the oil circuit breaker is not based on any oil circulation, but is based on the control of the explosive forces developed at the break, for extinguishing the arc, and you can easily realize, then, that the concentric gun barrel type of switch has advantages which no other type has as yet been able to approach.

Regarding the induction generator, I have always been very much in favor of it, and I believe it is a very useful machine; and in a central station having an excessive momentary short circuit current, the addition of the induction generator reduces the percentage of short circuit current, since this machine does not add to the short circuit current. But you must realize that you could get the same effect by using generators with lower regulation. Thus, if you consider the station as a whole,

Digitized by Google

there is little difference between a synchronous generator station and an induction generator station, regarding the momentary short circuit current. Every station depends in its excitation on an independent direct current excited field, in one case the synchronous alternator field, in the other case the synchronous motor field, which gives excitation to the induction generator. If you use for the excitation of the induction generator station the converters, synchronous motors, and frequency changers scattered over the system, as these are slow speed machines of low momentary short circuit current, you can materially reduce the short circuit current, but you throw the control of the system away from the generator station into the hundred or more isolated machines, all of which combine in controlling the generating station, and that is not practicable. If you have synchronous motor exciters floating on the system at the induction generator station, economy requires just as high speed machines as our present synchronous turbo-alternator, that is, machines with just as high momentary short circuit current, and you gain practically nothing; and therefore, while the induction generator is a very valuable machine in many instances, the problem of momentary short circuit current is not solved by it. The main field for the induction generator, in my mind, is in the secondary generating stations of hydroelectric systems, as it becomes possible thereby to control voltage, load and frequency of the system from a few main generating systems; the installation control and operation of the smaller induction generator stations becomes greatly simplified, and it becomes feasible to utilize smaller water powers, which could not be economically developed by synchronous machinery.

The last point I wish to bring up is the question of internal reactance as against separate reactance in the generator. That is a question which needs no further discussion, but is ancient history. The development of the generating station has long advanced beyond it. We know we must have power limiting reactance in the individual generator, and it is merely a constructive question—a question of design, whether we put it inside the alternator or outside of it, or whether we make the most economical combination possible, put into the machine as much reactance as possible without sacrificing the quality of the machine, and then put the rest of it outside of the machine.

But even if we had generators with a momentary short circuit current five or six times full load current, that would not solve the question of the operation of the present systems, because if the system is large enough, 100,000, 200,000 or 500,000 kw., you reach a limit where the operation becomes unsafe, even with power limiting generator reactances.

That is where the development has arrived, to put power limiting reactances in the bus-bars. This is really the most essential advance. In the last few years we have come to larger and larger systems, and consequently greater difficulties of

Digitized by Google

operation. Apparatus which was satisfactory in a 50,000-kw. station became unsuited to the operation of a 100,000-kw. station, and apparatus which had been employed in a 100,000-kw. station will become inoperative at 500,000 kw. That was not the case in the old Edison direct current system. There, if you joined generating stations together, there was no material increase of danger, no decrease of safety, because the whole system was limited by the resistance of lines and feeders. Thus the effect of a short circuit was practically the same, whether the station was alone, or other stations were tied to it; that is, there was that feature that the danger did not increase with the increase of the system. That is the most important feature which modern development has arrived at in these alternating current systems, that by breaking up the bus-bars and tie-feeders by reactances, the danger and difficulty of operation, the strain of switches and apparatus, does not increase with any further increase of the system, and the 100,000 kw. system is just as safe or dangerous as the same system will be if extended to 500,000 or 600,000 kw. capacity. That is the great development beyond the power limitation of the generator—the use of power limiting reactances in the bus-bars, which makes an unlimited extension of the system possible without any increase of danger.

Digitized by Google

Digitized by Google

NEXT REGULAR MEETING, NEW YORK, NOV. 10, 1911

Subjects: VON HELMHOLTZ BUST PRESENTATION; PROPERTIES OF IRON AT 200,000 CYCLES See page 289

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

UNIVERSITY OF MINNESOTA
THE LIBRARY
N 16 1911
RECEIVED

Volume XXX
Number II

November, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

A. I. E. E. Meeting, New York, November 10, 1911 - - - 289
Von Helmholtz Bust Presentation - - - - - - - 289
Future Section Meetings - - - - - - - 289
Resume of Business Transacted at A. I. E. E. Directors Meeting held October 13, 1911 - - - - - - - 289
A. I. E. E. Meeting in New York, October 13, 1911 - - - 292
New Sections and Branches - - - - - - 294
Associates Elected October 13, 1911 - - - - - 295
Applications for Election - - - - - - 298
Students Enrolled October 13, 1911 - - - - - 298
Recommended for Transfer - - - - - - 299
Telephone Transmission Engineering - - - - - 299
Proposed A. I. E. E. Trip to the Panama Canal Zone - - - 300
Past Section Meetings - - - - - - - 302
Past Branch Meetings - - - - - - - 305
Personal - - - - - - - - - 308
Obituary - - - - - - - - - 308
Library Accessions - - - - - - - 310

Section II. Papers, Discussions, and Reports

(For table of contents under this head see page 319.)

Index to Advertisements - - - - - - - III

Copyright 1911, by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y. December 17, 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

JUST PUBLISHED

A SHORT COURSE IN THE TESTING OF ELECTRICAL MACHINERY

For Non-Electrical Students.

PROF. J. H. MORECROFT and F. W. HEHRE
both of Columbia University

The testing of electrical machinery is here presented so as to be interesting and useful to the student of engineering who is specializing in the non-electrical branches but who may be called upon to make such tests in his subsequent practice. This is essentially a college text to be used in connection with a laboratory course. The object is to analyze, in non-mathematical language, the characteristics of the most important types of electrical apparatus with which the practicing engineer may come in contact, so as to familiarize the student with the methods for testing and to encourage a correct interpretation of the results obtained.

160 pages 6¼x9½. 84 illustrations. Net, $1.50.

THE PROPAGATION OF ELECTRIC CURRENTS IN TELEPHONE AND TELEGRAPH CONDUCTORS

PROF. J. A. FLEMING, M.A., D.Sc., F.R.S.

In this book an eminent authority has brought together in correlated sequence much information, which although available was scattered through many periodicals and a study of which required a mathematical knowledge generally beyond the attainments of the practical telephone and telegraph engineer. The simple mathematical introduction written by Dr. Fleming will make easy the acquirement of a working knowledge of the mathematical operations required in conducting the necessary calculations in connection with the subject. The theoretical treatment is simple so as to make the book useful to all telegraphists and telephonists.

330 pages, 5¾x9. Illustrated. Net, $3.00.

OTHER RECENT BOOKS

ELECTRIC TRACTION AND TRANSMISSION ENGINEERING

PROF. SAMUEL SHELDON and ERIC HAUSMANN.
both of Brooklyn Polytechnic Institute

317 pages. 5½x8. 127 illustrations. Net, $2.50.

SECOND EDITION, ENLARGED

DIRECT AND ALTERNATING CURRENT MANUAL

PROF. FREDERICK BEDELL and C. A. PIERCE
both of Cornell University

360 pages. 6x8¾. Illustrated. Net, $2.00.

ELECTRIC CENTRAL STATION DISTRIBUTION SYSTEMS

H. B. GEAR and P. F. BARNES. Associate Members A.I.E.E.

352 pages 6x9. 139 illustrations. Net, $3.00.

THE DESIGN OF STATIC TRANSFORMERS

H. M. HOBART, Mem. Inst. C. E.

190 pages. 5½x8¾. 100 illustrations. Net, $2.00.

CONTINUOUS CURRENT MACHINE DESIGN

PROF. WILLIAM CRAMP, M. I. E. E.

260 pages. 5½x8¾. 137 illustrations. Net, $2.50.

D. VAN NOSTRAND COMPANY

Publishers and Booksellers

23 MURRAY AND 27 WARREN STREETS - - NEW YORK

SEND FOR OUR CATALOG OF ELECTRICAL BOOKS

Digitized by Google

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX **November, 1911** No. 11

A. I. E. E. Meeting, New York, November 10, 1911

The two hundred and sixty-fifth meeting of the American Institute of Electrical Engineers will be held in the Engineers' Building, 33 West 39th Street, New York City, on Friday, November 10, 1911, at 8:15 p.m. Following the ceremonies of the von Helmholtz bust presentation, as announced on this page, a paper entitled "Magnetic Properties of Iron at Frequencies up to 200,000 Cycles", will be presented by Mr. E. F. Alexanderson, of the General Electric Company. Advance copies may be obtained on application to Institute headquarters.

Von Helmholtz Bust Presentation

An excellent bronze bust of the great German scientist, Hermann von Helmholtz, has been presented to the Institute by Mr. Edward D. Adams. A public acknowledgment of this valuable addition to the historical collection of the Institute, will be a feature of the Institute meeting in New York, November 10, 1911. It is expected that Mr. Edward D. Adams, the donor, will be present at this meeting, and arrangements have also been made for an address in behalf of the Verband Deutscher Elektrotechniker by Dr. Adolf Franke, who is at present in this country, and who was a student under von Helmholtz.

Future Section Meetings

Chicago

The schedule of the joint meetings of the Chicago Section and the Electrical Section of the Western Society of Engineers so far as has now been decided upon is as follows:

October 25: Dr. Charles P. Steinmetz; subject, "Reactance in Alternating Current Circuits."

November 22: Mr. F. F. Fowle; subject, "Going Value."

December 27: Mr. James Lyman; subject, "Protection of High Tension Power Circuit Apparatus."

January 28, 1912: Mr. W. J. Hagenah subject, "Public Utility Commissions."

Washington, D. C.

The November meeting of the Washington Section will be held in the Telephone Building on Tuesday, November 14. A local speaker will deliver an address, the subject and the name of the speaker to be announced later.

Resume of Business Transacted at A.I.E.E. Directors' Meeting Held October 13, 1911

One of the most largely attended directors' meetings of the Institute in recent times was held on October 13, 1911, promptly at half past three. There were present 18 out of the maximum number of 23 of the directors, as follows: President Gano Dunn, New York; Junior Past-President Dugald C. Jackson, Boston; Vice-Presidents H. W. Buck, Percy H. Thomas and Willard G. Carlton, New York; David B. Rushmore and Charles W. Stone, Schenectady; Managers Arthur W. Berresford, Milwaukee; William S. Murray, New Haven, Henry H. Norris,

Digitized by Google

Ithaca; Robert G. Black, Toronto; Fred S. Hunting, Fort Wayne; Farley Osgood Newark; Severn D. Sprong, Howel H. Barnes, Jr. and W. S. Rugg, New York; Treasurer George A. Hamilton, Elizabeth; and Acting Secretary F. L. Hutchinson, New York.

The Finance Committee's approval of monthly bills of the Institute, amounting to $5,047.26. was ratified, and the budget presented by the Finance Committee covering proposed expenditures amounting to $94,000.00 for the various activities of the Institute during the appropriation year beginning October 1, 1911, was adopted.

On the report of the Meetings and Papers Committee that the Portland, Oregon, Section had requested that the next Pacific coast meeting be held in Portland in 1912, it was

Resolved: that there be held in Portland, Oregon during April, 1912, a meeting of the Institute of the same character as the two previous Pacific coast meetings, provided that the manuscripts for a proper program of papers be in the hands of the Meetings and Papers Committee before March 1, 1912, and provided that other conditions which the discretion of the Meetings and Papers Committee considers requisite be met, the exact date of the meeting to be determined by the committee.

The Meetings and Papers Committee also urged upon the Board of Directors the importance of appointing at an early date a committee to decide upon the location of the annual convention for 1912. The Board agreed as to the desirability of an early settlement of the place of the convention, but instead of appointing a special committee to investigate and report upon the question, asked the Meetings and Papers Committee to undertake the task and to report finally upon the matter to the December meeting of the Board.

The report of the Board of Examiners' meeting of October 6 was read and approved. Eighty-six Associates were elected, and forty-four students were ordered enrolled. The following Associates were transferred to the grade of Member: Louis E. Bogen, Milwaukee; William G. Chace, Winnipeg, Man.; Markham Cheever, Provo, Utah; George L. Knight, Brooklyn; Alten S. Miller, St. Louis; Leo. A. Phillips, Milwaukee, and J. G. Wray, Chicago.

A University Branch was authorized at the Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, and another at Yale University, New Haven, Conn.

The Law Committee reported its interpretation of the provisions of the Constitution providing for second nominees on the directors' ticket of nominees and gave the opinion that the request of two members of the Board for the naming of a second nominee operated of itself, without further ballot, to put the name of such nominee upon the directors' ticket.

The President announced the appointment of Mr. W. D. Weaver to serve as a member of the Edison Medal Committee for five years, and also informed the Board that the following members had been appointed on the United States National Committee of the International Electrotechnical Commission: Messrs. C. O. Mailloux, President, Arthur E. Kennelly, Secretary, Comfort A. Adams, Louis Bell, John J. Carty, Carl Hering, John W. Howell, John W. Lieb, Jr., Ralph D. Mershon, Edward B. Rosa, Charles F. Scott, Clayton H. Sharp, Samuel Sheldon, Charles P. Steinmetz and Samuel W. Stratton.

The committee appointed at the August meeting of the Board to welcome and entertain Mr. S. Z. de Ferranti, President of the Institution of Electrical Engineers of Great Britain, visiting the United States, reported that it had given a luncheon in honor of the distinguished guest, which was attended by, in addition to Mr. de Ferranti and the other guests of honor, nine past-presidents and fifteen officers of the Institute.

A report was presented from Professor Morgan Brooks, acting chairman of the Institute delegation to the Third National Conservation Congress held in Kansas City in September, and his

Digitized by Google

recommendations were referred to the Public Policy Committee for report.

A letter and telegram from Mr. John H. Finney urging immediate coöperation of the Institute in a hearing before the Inland Waterways Commission, of which Senator Burton is Chairman, was read and referred by the Board to the Public Policy Committee.

On the invitation of the International Society for Testing Materials, the President was authorized to appoint a delegate to represent the Institute at the Sixth Congress of that society, to be held in September, 1912.

The President presented the report of Dr. Kennelly, Secretary of the United States National Committee of the International Electrotechnical Commission, and Secretary of the Institute delegation to the International Electrical Congress at Turin, which report was ordered printed for record in the PROCEEDINGS and TRANSACTIONS. The Board expressed its thanks to Dr. Kennelly for the care with which the report had been prepared.

The Secretary was instructed to publish with the Standardization Rules of the Institute the decisions of the International Electrotechnical Commission at Turin in regard to standard symbology, the direction for indicating advancement of phase in graphic diagrams of alternating current quantities, and a resume of the principles of the rating of electrical machinery of the leading foreign countries.

In view of the cordial hospitality shown by the Italian authorities and members of the Associazione Elettrotecnica Italiana to the representatives of the United States and the American Institute of Electrical Engineers attending the Congress at Turin, the President was requested to appoint a committee to draft suitable resolutions expressing the appreciation of the Institute for the honors and distinctions the American representatives had received.

The following resolution was adopted:

Whereas, the progress of research in electrophysics has demonstrated the intimate relation between this subject and many practical questions of electrical engineering, and

Whereas, the great practical importance and increasing amount of engineering experimental research in subjects relating to high tension transmission, electrochemistry, the behavior of insulating materials, and electric illuminations requires the study and discussion of electrophysics, it is

Resolved: that the Board of Directors of the American Institute of Electrical Engineers hereby authorizes the President to add a committee on electrophysics to the standing technical committees of the Institute, and to appoint on the committee the same number of members as are appointed on the other technical committees of the Institute.

In view of the resolution proposed and carried with much applause at the International Electrical Congress at Turin, complimenting the American Institute of Electrical Engineers on its practice of inserting in its publications the metric equivalent value in parentheses after each expression of values in English measures, and in view of the request of the Congress that the technical societies of all countries in which the metric system is not yet official be invited to follow the example of the American Institute of Electrical Engineers, it was

Resolved: that the Board of Directors requests the Editing Committee to regard as standard practice and to continue the insertion of metric equivalents, and to include in its "Suggestions to Authors" the request that the authors themselves, as far as possible, make the metric insertions in order to facilitate the work of the Editing Committee. It was also

Resolved: that the Institute adopt the standard international symbology decided upon by the International Electrotechnical Commission, and that the Editing Committee be requested to include in its "Suggestions to Authors" the request that, as far as possible, the authors of all papers also adopt this symbology. It was also

Resolved: that the Institute adopt as the standard direction for expressing advancement of phase in graphic diagrams of alternating current quantities the counter-clockwise direction standardized by the International Electrotechnical Commission, and that the Editing Committee be requested to ask the authors of Institute papers, as far as possible, to use this standard direction in diagrams prepared for publication in the Institute TRANSACTIONS.

Digitized by Google

The meeting closed with the adoption of the following resolution, offered by Past-President Jackson:

Resolved: that the Board of Directors hereby expresses its appreciation of the distinguished services of President Dunn, Chairman Mailloux, Secretary Kennelly, Dr. Sharp, and of the President of the International Commission, Dr. Elihu Thomson, and their associated American delegates to the International Electrical Congress at Turin, in representing the Institute with gratifying enhancement of its reputation and dignity in the functions and meetings of the Congress and of the International Electrotechnical Commission.

A. I. E. E. Meeting in New York, October 13, 1911

The two hundred and sixty-fourth meeting of the American Institute of Electrical Engineers was held in the Engineers' Building, 33 West 39th Street, New York City, on Friday, October 13, 1911. The meeting was called to order by President Gano Dunn promptly at 8:30 p.m. Acting Secretary Hutchinson announced the election of 86 Associates at the meeting of the Board of Directors held during the afternoon, and the transfer of seven Associates, whose names appear elsewhere in this issue, to the grade of Member; also that the Board had authorized Branches of the Institute at Yale University and the Oklahoma Agricultural and Mechanical College. President Dunn then gave a brief account of some of the more important results of the International Congress at Turin and the meeting of the International Electrotechnical Commission, as follows:

"As you all know, there was held this year at Turin another of the International Electrical Congresses to which our industry and our science has owed so much in the past, and it has set a pace that is no less than the pace that has in the past been set by the congresses at Marseilles, at Paris, at London, at St. Louis, at Chicago, and so on. It is a fact of which the American Institute of Electrical Engineers ho uld be proud that it has had from the beginning a very important part in the calling and in the success of these congresses. The part that the American Institute of Electrical Engineers has played has been fully recognized again this year; and in the future, while congresses no longer are to be called by the last congress that is in session, as the calling of them has been left to a permanent body—the International Electro'echnical Commission—I know you will be glad to hear that the first congress called by this very important body is a congress at San Francisco in 1915, here in America. So we are on record again as having been honored by the first congress which has been the result of the decision of the new body on congresses—the International Electrotechnical Commission.

"The function of the commission is exactly what was intended to be its function when it was created at the American Congress held in St. Louis in the year 1904. It has been organized for the purpose of standardizing the matters of nomenclature, rating, symbology, and other similar things necessary to make electrical engineers in one part of the world understand electrical engineers in another part of the world. There have been many attempts toward an international language. Very few realize that the language of mathematics is international in its form, but is not yet—and especially in the realm of electrical engineering—international in its symbols. For several years the commission has busied itself with making the symbols that shall be used in the equations written by electrical engineers the same the world over. A very simple formula, with which you are all familiar, has presented some of the greatest difficulties—the old formula for Ohm's law. You all know that the English form of that law has been from the beginning: C equals E divided by R, and the German form of that law has been I equals E divided by W, and the French form of that law has been I equals E divided by R, and the mix-

Digitized by Google

tures of the *I*s and the *W*s and the *C*s has been such that when the members of that equation are worked up into any particular degree of work it has not been quite certain what the symbols meant. The Germans did not want to give up their term for resistance and the English did not want to give up their "current," but finally, this year the Germans voluntarily proposed to give up *W* for resistance and use *R*, provided the English would give up *C* for current and use *I* for intensity. That was accomplished amid much enthusiasm and applause and the fact now stands that all over the world *I* equals *E* divided by *R*.

"This is only one instance, and a very simple one, of what the commission has been doing. At Turin there was adopted a list of other symbols of which the principal characteristics are these. Capital letters it was decided should be used for the expression of maximum values; small letters for the expression of periodic quantities; Roman letters for the ordinary quantities that we deal with; Clarendon face or fat face or special face letters for magnetic quantities, and so on.

"With the adoption of these standards and as they become introduced, an equation written by a German will have the same symbols as an equation written by an American, and there will no longer be that difficulty in reading that we have all often experienced in reading the formulas in the various text-books or in various papers when we have not been quite sure of what the symbol stood for.

"More than the question of symbology is the question of nomenclature. What does brush-holder mean? These questions have been worked up very carefully, and while on the question of nomenclature final results have not been accomplished they are in course of accomplishment, and results are to be hoped for soon.

"You are all aware that while in England what has been rather inaccurately termed the direction of rotation of vectors has been counter clock wise universally; in France counter clock wise universally; in Italy counter clock wise; in Sweden, Norway, Russia, Japan, all counter clock wise universally. In Germany it has been about equally divided between direct or clock wise and counter clock wise, and in the United States it has been about equally divided also. That matter has been before the commission for a year, and the commission has unanimously expressed the decision that in the graphical representation of alternating current quantities the direction in which phase shall be considered to advance shall be the counter clock wise direction—and that decision was also unanimously adopted after the Germans among themselves had decided that that was the best direction.

"This decision now means that if an engineer who has been educated in Germany goes to a blackboard to make a diagram, he will show—for instance, if the electromotive force shall be represented by the position of the hands of the clock, we will say, and the hour hand points to one o'clock a lagging current will be represented by the position of the hand pointing to two o'clock, and not pointing to twelve o'clock. Now, this is a great advantage, as you all know.

"The Institute of Electrical Engineers has been accustomed during the past year to put in parenthesis, after the expression of values, in the English measure, in its papers, the equivalent values in measures, in the metric system; so that the papers would be of more value to members and others living in metric system countries. When you realize, for instance, that even an Englishman cannot properly read a paper of the American Institute of Electrical Engineers and safely go by it, since the English ton is different from our ton. and the English gallon from our gallon, and the English bushel—which in fact we do not use, is different from our bushel, all of which a large number of engineers in England do not know in

Digitized by Google

respect to the United States, and a large number of engineers in the United States do not know in respect of England; when you realize this you will see that this expression of metric values after their values is of use even in non-metric countries.

"So great was the appreciation of the six hundred and forty-five delegates from all over the world to the International Congress at Turin of this practice of the American Institute of Electrical Engineers, which, as far as I was able to learn, is the only technical body that has started to do it, that they passed first in unofficial session, a resolution, which was later confirmed by the plenary session of the Congress, complimenting the American Institute of Electrical Engineers for this practice, and pointing out how much it increased the value of the papers of the American Institute of Electrical Engineers to members, and to others in foreign countries. And, what is a most signal honor, it called upon all technical societies in all other countries to follow the noteworthy example of the American Institute of Electrical Engineers.

"The American delegation was treated with unusual courtesy and with high honor by the Italian officers of the Congress, and the members of the Italian Association of Electrical Engineers. We were unique in having first the very high honor of a Vice-Presidency of the whole Congress given to the President of the American Institute of Electrical Engineers, as such, and the Presidency of two of the Sections of the Congress, of which there were about eight given to Americans. Those were honors that were not given to other nations attending.

"The enthusiasm with which the Congress and the Commission took up the idea of an International Electrotechnical meeting and an International Electrical Congress at San Francisco in the year 1915 on the celebration of the opening of the Panama Canal, was most gratifying to us, and the spirit with which the Swiss, who wanted the next Congress, and the Germans who also wanted it, withdrew in favor of the Americans, was most friendly and coöperative.

"It is a great pleasure for me to give you this short account of these things, as I know as members of the American Institute of Electrical Engineers you are interested in seeing how many courtesies have been shown to your representatives abroad, and in seeing how much weight is given to some of the things in which the American Institute of Electrical Engineers has taken the lead."

An extended report of both of these meetings will be found in this number.

At the conclusion of his remarks Mr. Dunn introduced Mr. B. G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, who presented in abstract his paper on "A Theory of Commutation and Its Application to Interpole Machines", which will be found printed in the October PROCEEDINGS. Considerable discussion followed by Messrs. Erben, Hoxie, Hobart, MacLaren, Adams, Scott, Burke, Treat and Wilson.

New Sections and Branches

At the meeting of the Board of Directors of the Institute held on August 22, new Sections were authorized at Lynn, Mass., and Vancouver, B. C. The Lynn Section has already held several meetings, and over 350 members have been enrolled. A report of the first meeting will be found elsewhere in this issue.

At the meeting of the Board held on October 13, new Branches were authorized at Yale University, New Haven, Conn., and the Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma.

This brings the number of Sections up to 25, and the number of Branches to 38.

Digitized by Google

Associates Elected October 13, 1911

ABBOTT, LEWIS WILLIAM, Assistant Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.

AHLSTROM, WALTER, Operator, North Shore Electric Co., Highland Park; res., 1424 N. Artesian Ave., Chicago, Ill.

ALDEN, LOYAL REMELE, Construction Engineer, General Electric Co., 7 East German St., Baltimore, Md.

BELL, WILLIAM CONSTANTINE, Pacific Gas and Electric Co., San Francisco; res., Vallejo, Cal.

BERRY, EDWARD ROBIE, Chemist, General Electric Co., Lynn; res., 105 Cross St., Malden, Mass.

BIRELEY, ROBERT MORRIS, Appalachian Power Co., Bluefield, W. Va.

BIRKS, LAWRENCE, Electrical Engineer, Public Works Department, New Zealand Government, Wellington, N. Z.

BLACKLEY, SAMUEL, Engineer and General Manager, Turnbull & Jones, Ltd., Blair St., Wellington, N. Z.

BROGGINI, ANDREW, Electrical Engineer, Publicity Div., National Carbon Co., Cleveland, Ohio.

BUSBY, NAHUM J., JR., Clerk, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., 50 Nichols St., Chelsea, Mass.

CHAPMAN, CHARLES HERBERT, Student Engineer, General Electric Co.; res., 204 Lafayette St., Schenectady, N. Y.

CHURCH, SANFORD E., Chief Electrician, Sears, Roebuck & Co.; res., 3224 Monroe St., Chicago, Ill.

COCHRAN, CLYDE ERNEST, Electrical Engineer, Elwell-Parker Electric Co., 4223 St. Clair Ave.; res., 10925 Churchill Ave., Cleveland, Ohio.

DE BLOIS, THOMAS MELVILLE, Smith, Kerry and Chace, Confederation Life Bldg.; res., 214 Russell Hill Drive, Toronto, Ont.

DEMING, LUCIUS FOY, Engineer, General Electric Co., Witherspoon Bldg.; res., 114 East Gowen Ave., Philadelphia, Pa.

DE VILBISS, EDWIN BOWSER, Motive Power Inspector, Pennsylvania Co.; res., 2714 Holton Ave., Fort Wayne, Ind.

DEWHURST, JOHN ALFRED, Engineer, General Electric Co.; res., 211 Seward Pl., Schenectady, N. Y.

DOUGLAS, HENDERSON BLACK, Manager of Works, Standard Steel Car Co.; res., 51 Glendale Park, Hammond, Ind.

DRAKE, ROBERT WARREN, Electrical Engineer, International Harvester Co., McCormick Works, Chicago, Ill.

DUNBAR, GLENDOWER, Electrical Engineer, City of Seattle Lighting Dept., res., 4009 41st Ave., S. Seattle, Wash.

EHMKE, HENRY CHRIST, JR., Electrical Engineer, Moline Plow Co.; res., 2739 8th Ave., Rock Island, Ill.

ELSMAN, RALPH, Assistant to Engineer of Electrical Distribution, Pacific Gas & Electric Co., San Francisco, Cal.

EVERS, ALBERT EDMOND, Electrical Worker, Southern Pacific Co.; res., 110 Evans Ave., Oakland, Cal.

FARWELL, STANLEY PRINCE, Instructor in Mechanics University of Illinois; res., 905 S. 6th St., Champaign, Ill.

FENNESSY, DAVID VINCENT, Manager, Parral Power & Reduction Co., Apartado 71, Parral, Chih., Mexico.

FROST, WILLIAM BARRET, Assistant in Sales Dept., Wagner Electric Mfg. Co., res., 4512 W. Pine Blvd., St. Louis, Mo.

GEBHARDT, CHARLES WENDEL, Power Plant Operator, Northern California Power Co., 2395 Vallejo St., San Francisco, Cal.

GLANDER, EDWARD LOUIS, Switchboard Installer, Dakota Central Telephone Co., Aberdeen, S. D.

GREENWALD, GEORGE, Electrical Engineer, Tramway Commission, Nadejdinskaja Street 38, St. Petersburg, Russia.

HALL, HENRY MONROE, Assistant Superintendent, Aluminum Company of America, Massena, N. Y..

Digitized by Google

HAYDEN, THOMAS J., Electrical Instructor, Dept. of Correction, Harts Island; res., 346 West 145th St., New York City.

HENNING, CHARLES SUMNER, JR., Division Engineer, Oregon Short Line Railroad Co., Richfield, Idaho.

HOLLAND, HENRY NORMAN, Chief Assistant Electrical Engineer, Kolar Gold Field, Electricity Dept., Mysore State, S. India.

HOWE, CHARLES FISHER, Chief Engineer, Central Georgia Power Co.; res., 1420 Hazel St., Macon, Ga.

HOYER, OLE S., Draftsman, New York Edison Co., 55 Duane St.; res., 5614 4th Ave., Brooklyn, N. Y.

HUSSEY, HENRY ALBERT, Sales Engineer, Westinghouse Lamp Co., Bloomfield; res., 192 Prospect St., E. Orange, N. J.

ISBISTER, JOHN, Electrical Engineer, Mond Nickel Co., Victoria Mines, Ont.

JOHNSON, FRANK E., Manager, Ohio Brass Co., 508 Fisher Bldg.; res., 5841 Calumet Ave., Chicago, Ill.

KEENEY, W. EARLE, Electric Meter Foreman, Municipal Light & Power Plant of Seattle; res., 1602 No. 53rd St., Seattle, Wash.

KENNEY, WILSON CARSON, Electrical Engineer, Buick Motor Company; res., 1808 North Saginaw St., Flint. Mich.

KREMER, WALDEMAR RUDOLF, Vilter Mfg. Co.; res., 679 Marshall St., Milwaukee, Wis.

LEIBOLD, CARL PETER, Salesman, Ohio Brass Co.; res., 229 West 11th Ave., Columbus, Ohio.

LINDEM, MARTIN, Superintendent, The Battery Company, Railroad Exchange Building, Milwaukee, Wis.

LONG, RICHARD HENRY, Assistant Superintendent, Winnipeg Electric Railway Co., Pinawa, Man.

LOWRY, JOHN EDMUND, Chief Switchman, City of Edmonton Telephone Dept.; res., 12 Chisholm Block, Edmonton, Alta.

LUSTIG, LEO, Elecrical Engineer, General Electric Co.; res., 401 Congress St., Schenectady, N. Y.

MARTIN, DOUGLAS SUTHERLAND, Assistant Editor, General Electric Review, General Electric Co., Schenectady, N. Y.

MCHENRY, MORRIS JAMES, Electrical Designer, Smith, Kerry & Chace, Confederation Life Bldg., Toronto, Ont.

MCKEEN, FRANK SMITH, Sub-Foreman of Inside Construction, City of Seattle Lighting Department, Seattle, Wash.

MCKENNEY, LESTER, Electrical Engineer, Garner Print Works & Bleachery, Wappingers Falls, N. Y.

MCKNIGHT, CHARLES HENRY, Assistant Foreman Meter Dept., Allegheny County Light Co.; res., Pittsburg, Pa.

MILTON, TALIAFERRO, District Engineer, Electric Storage Battery Co., 1426 Marquette Bldg.; Chicago, Ill.

MONTGOMERY, THEODORE D., Sales Engineer, Cutler-Hammer Mfg. Co., 1483 Hudson Terminal Bldg., 50 Church St., New York City.

MURRAY, JOHN DUNCAN, Sales Engineer, Continental Electric Co., 221 S. Clinton St.; res., 907 Alexander Pl., Chicago, Ill.

NORDENSVAN, GUSTAF MAGNUS, Draftsman, Stone & Webster Engineering Corporation, 308 I. O. O. F. Building, Reno, Nev.

OGUR, EUGENE, Allied Engineering Co., 546 5th Ave., New York City; res., 7 Flushing Ave., Astoria, L. I., N. Y.

OVERTON, THOMAS RICHARD, Electrical Engineer, Electrical Dept., City Corporation, Dunedin, New Zealand.

PFEIFER, JOSEPH W., Assistant Chief Electrician, Sears, Roebuck & Co., Chicago; res., 430 Beloit Ave., Forest Park, Ill.

POLHEMUS, LOUIS EDWARD, Mechanical and Electrical Engineer, Cubo Mining & Milling Co., Guanajuato, Mex.

Digitized by Google

REED, HARRISON PIERCE, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 169 16th St., Milwaukee, Wis.

REINKE, A. E., Chief Engineer, Western Electric Co., Salz Ufer 7, Charlottenburg, Berlin, Germany.

REYNOLDS, WALTER HAROLD, Manager, E. F. Phillips Electrical Works, Ltd., 603 Union Bank Bldg., Winnipeg, Man.

RIEBEL, FREDERICK, JR., General Superintendent, Southern Indiana Power Co., Bedford, Ind.

RITCHIE, RAYMOND R., Equipment Inspector & Instructor, Oklahoma Ry. Co.; res., 404 E. 11th St., Oklahoma City, Okla.

ROSENTHAL, HARRY, Rosenthal Electric Laboratory, 502 Perry Building, Philadelphia, Pa.

SAINZ, JOSEPH MARIE, Electrical Engineer, Societe Industrielle des Telephones, 22, Rue Rolland, Bordeaux, France.

SERVA, ADAM AMOS, Sales Manager, Fort Wayne Electric Works; res., 2420 Hoagland Ave., Fort Wayne, Ind.

SIDLER, LUIS JOSE, Electrical Engineer, Compania Alemana Transatlantica de Electricidad, Casilla Correo 1191, Buenos Aires, A. R.

SMITH, HOWARD AUSBURN, Electrical Engineer, General Electric Co.; res., The Blaisdell, Pittsfield, Mass.

STANLEY, JACK, Superintendent of Transportation, Trinidad Electric Transmission Ry. & Gas Co., Trinidad, Colo.

STEELE, ELIJAH HUBERT, Pacific Gas & Electric Co., San Francisco; res., 2313 Mitchell St., Fruitvale, Cal.

STEINICKE, FRANK HERMAN, Electrical Draftsman, General Electric Co; res., 514 Union St., Schenectady, N. Y.

STOCKS, BRAINERD RAE, Student Apprentice, General Electric Co. Pittsfield, Mass.

STOKES, HARRY RUSSELL, Power Engineer, N. Y. & Queens Electric Lt. & Pr. Co., Long Island City, N. Y.

TIFFT, GEORGE L., Assistant to Consulting Engineer, Allis-Chalmers Co., Milwaukee; res., Wauwatosa, Wis.

TUCKER, WILLIAM HARRISON, Construction Department Expert, Fort Wayne Electric Works, 30 Church St., New York City.

TUPPER, HIRAM BENNETT, Supervisor of Testing, Pacific Tel. & Tel. Co.; res., 1925 Ellendale Ave., Los Angeles, Cal.

VAN DYKE, CLIFFORD STEELE, Superintendent Operating Dept., Schenectady Illuminating Co., 511 State St., Schenectady, N. Y.

VAN STEEDEN, MARGRETHUS CORNELIS WILLEM, JR., Electrical Engineer, 316 West 22d St., New York City.

VOLIO, JOSE JOAQUIN CARRANZA, Electrical Engineer, Purdy Engineering Co., San Jose, Costa Rica.

WALLOWER, CHARLES WILLIAM, District Plant Chief, American Tel. & Tel. Co.; 293 Triangle St., Buffalo, N. Y.

WARD, BALDWIN D., Northern California Power Co., Coleman Power House, Ball Ferry, Cal.

WICKMAN, JAE HERBERT, Electrical Foreman, Illinois Central R.R.; res., 298 Walker Ave., Memphis, Tenn.

WOLFERSTAN, STANLEY HERCY PIPE, Inspector, Canadian Fire Underwriters; res., 88 Stanley St., Montreal, Que.

WORTMANN, OTTO, Switchboard Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 500 South Ave., Wilkinsburg, Pa.

ZSCHOCKELT, CARL GOTTHELF, Superintendent, Indian Valley Electric Light and Power Co., 1115 Crocker Bldg., San Francisco, Cal.

Total 86.

Digitized by Google

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before November 25, 1911.

10720 Pinto, A., New York City.
10721 Yoshida, K., Tokyo, Japan.
10722 Purcell, J. M., Richmond, Va.
10723 Rankin, F. J., Fort Collins, Colo.
10724 Channell, E. C., Kashmir, India.
10725 Cummings, J. A., Jr., Phila., Pa.
10726 Jenkins, J. E., Gatun, C. Z.
10727 Talbott, W. H., San Diego, Cal.
10728 Wilkins, H. E., Corozal, C. Z.
10729 Wardwell, C. M., Ann Arbor, Mich.
10730 Woodcock, F., Mexico, D. F.
10731 Bang, A. F., Baltimore, Md.
10732 Cole, D. S., Ithaca, N. Y.
10733 Dwight, H. B., Hamilton, Ont.
10734 Haff, H. L., Redondo Beach, Cal.
10735 Head, H. G., Fort Wayne, Ind.
10736 Moore, L. A., Perth Amboy, N. J.
10737 O'Keefe, H. J., Vancouver, B. C.
10738 Phelps, A. F., Gulf, W. Va.
10739 Solitro, A., Schenectady, N. Y.
10740 Stewart, C. H., London, Eng.
10741 Sultan, W. D., San Francisco, Cal.
10742 De Cew, T. L., Winnipeg, Man.
10743 Early, J. W., Denver, Colo.
10744 Purdon, A., Wilkinsburg, Pa.
10745 Rogers, S. C., Lynn, Mass.
10746 Womack, H. A., Lynn, Mass.
10747 Darcey, J. F., Washington, D. C.
10748 Ford, F. H., Milwaukee, Wis.
10749 Judson, L. B., New York City.
10750 Reid, C. L., Schenectady, N. Y.
10751 Alden, V. E., Wilkinsburg, Pa.
10752 Goldschmidt, E. H., Lynn, Mass.
10753 Lenker, L. E., Fayettville, Ark.
10754 Lockwood, A. C., Lynn, Mass.
10755 Winston, E. G., Pittsfield, Mass.
10756 Altes, W. C. K., Schenectady, N. Y.
10757 Harris, A. R., Orange, N. J.
10758 Karino, Y., Tokyo, Japan.
10759 Luckiesh, M., Cleveland, Ohio.
10760 McNair, G. B., St. Louis, Mo.
10761 Riley, R. A., Birmingham, Ala.
10762 Robbins, W., St. Louis, Mo.
10763 Roscoe, E. B., Buenos Aires, A.R.
10764 Rowland, E. W., E. Orange, N. J.
10765 Strong, W. W., Pittsburgh, Pa.
10766 Grubmeyer, A. B., Baltimore, Md
10767 Parker, H. L., Baltimore, Md.
10768 Roberts, R. B., Fort Wayne, Ind.
10769 Roehn, E. F., New York City.
10770 Carleton, F. V., Pittsburgh, Pa.
10771 Dobson, G. G., New York City.
10772 Field, W. C., Olneyville, R. I.
10773 Morrison, L. A., New York City.
10774 Weber, H. F., New York City.
10775 Gilmore, F. L., Guanajuato, Mex.
10776 Harding, P. H., Guanajuato, Mex
10777 Harris, Clayton, Houston, Tex.
10778 La Belle, E. P., Vancouver, B. C.
10779 Parham, J. B., Vancouver, B. C.
10780 Pertsch, J. G., Jr., Ithaca, N. Y.
10781 Wickman, C. T., Chicago, Ill.
10782 Anderson, J., Lynn, Mass.
10783 Brackett, R. D., Schenectady, N. Y.
10784 Fox, C. A., Nampa, Idaho.
10785 French, R. C., Lynn, Mass.
10786 Layng, John F., Annapolis, Md.
10787 Maier, G. A., Schenectady, N. Y.
10788 Merck, W. E., Easley, S. C.
10789 Eberhart, M. J. Newark, N. J.
10790 Davern, F.C.. Swampscott, Mass.
10791 Clark, W. S., Schenectady, N. Y.
10792 Benedict, E. E., Chicago, Ill.
19793 Agee, H.H., Shelburne Falls, Mass.
10794 Adams, P. H., Newark, N. J.

Total, 75.

Students Enrolled October 13, 1911

4518 Parker, W. L., New Zealand Univ.
4519 Jennings, C. E., Ohio State Univ.
4520 Sweet, H. S., Bucknell University.
4521 Greenleaf, M. C., Mich. Agr. Coll.
4522 Ambrose, G., Univ. of Michigan.
4523 Allured, K. B., Univ. of Michigan.
4524 Harden, W. H., Univ. of Mich.
4526 Rosenblatt, M. M., Case Sch. Sci.
4527 Curtis, M., Armour Inst. Tech.
4528 Adam, E. N., Stanford Univ.
4529 Crew, J. A., Univ. of Iowa.
4530 Kieser, L. J., Univ. of Iowa.
4531 Shapiro, S. R., Univ. of Wisconsin.
4532 Melcon, Z. P., Stanford Univ.
4533 Wade, G., Stanford University.

Digitized by Google

4534 Christopher, E. L., Univ. So. Cal.
4535 Stearns, C. F., Worc. Poly. Inst.
4536 Roberts, J. L., Worc. Poly. Inst.
4537 Riordan, D. J., Worc. Poly. Inst.
4538 Melcon, S. V., Stanford Univ.
4540 Vogliotti, H. F., State Univ. Ky.
4541 Taliaferro, R. R., State Univ. Ky.
4542 Shoemaker, H. B., State Univ. Ky.
4543 Saunders, S. D., State Univ. Ky.
4544 Ramsay, A. T., State Univ. Ky.
4545 Milligan, V. B., State Univ. Ky.
4546 Meadors, G., State Univ. Ky.
4547 Lowe, J. T., State Univ. Ky.
4548 Korfhage, H. G., State Univ. Ky.
4549 Kohn, E. J., State Univ. Ky.
4550 Karn, F. S., State Univ. Ky.
4551 Jones, R. L., State Univ. Ky.
4552 Jaegle, W. H., State Univ. Ky.
4553 Hollar, O. W., State Univ. Ky.
4554 Hardesty, L. C., State Univ. Ky.
4555 Galloway, H. C., State Univ. Ky.
4556 Gaiser, J. H., State Univ. Ky.
4557 Edelen, J. L., State Univ. Ky.
4558 Duncan, J. R., State Univ. Ky.
4559 Cary, J. W., State Univ. Ky.
4560 Beatty, T. E., State Univ. Ky.
4561 Ammerman, W. H., State Univ. Kentucky.

Total, 42.

Recommended for Transfer

The following Associates were recommended for transfer by the Board of Examiners at its regular monthly meeting held on October 6, 1911. Any objection to the transfer of these Associates should be filed at once with the Acting Secretary:

FREDERICK B. BROWN, Consulting Engineer, Montreal, P. Q.

ALLARD SMITH, Outside Plant Engineer, Chicago Telephone Company, Chicago, Ill.

JOSEPH N. G. NESBIT, Professor of Experimental Engineering, Georgia School of Technology, Atlanta, Ga.

EDWIN H. COLPITTS, Electrical Engineer, Western Electric Company, New York.

SAMUEL G. RHODES, Engineer, Meter and Test Dept., and Supt., Arc Lamp Dept., New York Edison Company, New York.

WALTON CLARK, Third Vice-President, United Gas Improvement Company, Philadelphia, Pa.

Telephone Transmission Engineering

A large audience gathered at the October meeting of the Washington Section of the A. I. E. E. to hear an address by Dr. F. B. Jewett, transmission and protection engineer of the American Telephone and Telegraph Company, on "Telephone Transmission Engineering." The title of the paper, as explained by the speaker, might well have been made to embrace both telephone and telegraph transmission engineering, so extensive and important has become the application of simultaneous simplex and duplex telegraphy to telephone circuits.

A brief outline was given of the scope of the engineering work which is carried on by the engineering departments of the American Telephone and Telegraph Company, and the several operating companies of the Bell Telephone System. A great deal of fundamental research and investigation is done by the engineers of the American Telephone and Telegraph Company while the field tests of new apparatus and methods are made by the engineers of the operating companies and many important improvements and ideas come from this latter source.

Referring to the necessity for "telephone transmission engineering," which has been recognized for only some 10 years past, Dr. Jewett called attention to some of the difficulties which are encountered in telephone transmission, but which are not met in power transmission problems. In the former, not only must an ample amount of energy be transmitted to the farther end of the line, but the form of the wave, which is very complex, must be accurately pre-

Digitized by Google

served. Again, while with power transmission only one or a few frequencies are used, a telephone circuit must be designed to carry a very wide range of frequencies; and while power transmission lines are but a fraction of a wave-length long, telephone transmission lines, on account of the great distances covered and the relatively high frequencies which are employed, are many wave-lengths long. Then, too, each telephone station in the system must be both generator and motor, and capable, at any instant, to act efficiently as either a generating or a receiving station. Finally, this generating and receiving apparatus must be so designed and constructed that it can be satisfactorily handled not by experts, but by the untrained public.

The adoption of standards of transmission was discussed and attention was called to the large number of different kinds of circuits which are now used in order to give transmission of the proper grade between the various parts of a system. At the present time paper insulated cables are being used with conductors of various sizes from No. 22 to No. 10 Brown and Sharpe gauge. For a given telephone area such as a large city, and its suburbs, the transmission problem consists principally in determining how a given grade of transmission which has been decided upon can be given at the lowest annual cost. It is customary in making transmission studies for definite telephone areas to anticipate the requirements of the community by approximately 15 years. For local service approximate forecasts for this length of time are made with reasonable reliability, but for toll and long distance service the future requirements are much more uncertain.

Referring specifically to the New York-Washington underground cable which is now being laid, Dr. Jewett spoke of the satisfactory basis upon which mathematical investigation of telephone transmission phenomena has now been placed. So definite and reliable are the formulas which have been developed for telephone transmission through circuits in open wire and in cable, unloaded and loaded with Pupin inductance coils, physical and phantomed, both with and without provision for simultaneous telegraphy over the same wires, that in the case of this enterprise, which involves an exceedingly large expenditure not only for cable and loading coils, but for the extension of the underground conduit system from Wilmington to Washington, the appropriation had been made and large expense incurred before the cable had been actually designed, and its installation is being completed in full confidence that the actual results in the grade of transmission which will obtain will not differ more than a few per cent from the calculated results.

The paper was discussed by Mr. H. Mouradian transmission engineer of the Bell Telephone Company of Pennsylvania, Mr. P. G. Burton, plant superintendent of the Chesapeake and Potomac Telephone Company, Major George Owen Squier, of the U. S. Signal Corps, and others.

Proposed A. I. E. E. Trip to the Panama Canal Zone

The Board of Directors has under consideration the suggestion of arranging for a trip of inspection to the Panama Canal Zone during the coming winter.

The work on the canal has reached such an advanced stage that by May, 1912, the authorities expect to begin flooding the Gatun Lake and letting water into the various levels of the canal. Therefore, this coming winter will afford the best, and also the last, opportunity of inspecting the work, as it will have approached completion without, however, any part of it being under water or impossible of easy inspection. The Board, therefore, regards this as a most opportune time to make an excursion for this purpose, and

Digitized by Google

the committee on the proposed trip has received unofficial assurances that every necessary facility and opportunity for a thorough examination of the work will be available.

Among the several propositions received, the committee has selected the following, which it is prepared to recommend:

The United Fruit Company has regular sailings from both New York and New Orleans, the steamer from the latter port sailing two days later than the steamer from the former port, both steamers arriving at Colon at the same time. These steamers are all practically new and have accommodations equal to any in their class. The maximum number that can be accommodated on a ship leaving either port is eighty-eight. It is hoped that the committee will receive sufficient applications to cover the capacity of two ships, one from New York and one from New Orleans, making a total of 176 passengers. The round trip from New York requires twenty-one days, and the round trip from New Orleans about seventeen days; this allows seven days on the Canal Zone. It is probable that the date of sailing from New York will be between January 20 and 30.

The round trip price per passenger would be $125.00 from New York, or $95.00 from New Orleans. No half fares. Because of the probable demand for accommodations the committee desires to limit the party to adults. These rates do not include any accommodations on the Isthmus. Accommodations may be obtained there, at the Tivoli Hotel, at the rate of $5.00 to $6.00 per day, American plan.

As the stopover of one week at Panama enables the excursionists to return on the same steamer, an interesting extension trip is available for those of the party who would not care to spend more than one and one-half days on the Isthmus. The steamers on the down trip remain one and one-half days at Colon and then proceed to the port of Santa Marta for the purpose of taking on cargo for New York or New Orleans. The round trip from Panama to Santa Marta takes about five days. Those who would care to extend their trip in this way could do so without extra charge.

As the excursion would be made on steamers of the United Fruit Company sailing on regular schedule, the company cannot undertake to reserve the total accommodations on any steamer for a period less than about six weeks before sailing time. In view of this condition and the important fact that the coming winter will be the best, as well as the last, favorable opportunity for an inspection of the canal work from an engineering point of view, it is necessary to make final arrangements as promptly as possible, as no doubt such an excursion, if decided upon, will prove a very popular one and the accommodations, limited to eighty-eight from each port, will be rapidly reserved.

To carry on successfully an undertaking such as that proposed it is necessary because of the late date, to obtain an expression of intention from the membership in as definite and prompt a manner as possible. Circulars relating to the proposed trip accompanied by return cards for the use of members who desire to participate, were mailed recently, and the committee hopes to receive a sufficient number of favorable replies to warrant it in making definite arrangement with the transportation company early in November. In this event reservation blanks will be sent immediately to the members who have expressed their intention to participate. It will then be necessary for these blanks to be returned promptly accompanied by 50 per cent of the cost of steamship accommodations.

COMMITTEE ON PROPOSED
PANAMA TRIP,

S. D. SPRONG,
Chairman.

Digitized by Google

Past Section Meetings

CHICAGO

The first meeting of the Chicago Section for this season was held on Wednesday evening, September 27, in coöperation with the Electrical Section of the Western Society of Engineers. A paper was presented by Mr. S. G. Neiler, entitled "The Electrical and Mechanical Equipment of the New Terminal of the Chicago and Northwestern Railway." This paper was the third of a series of three papers on the new terminal, and was discussed by Messrs. Seely, Ravlin, A. Bement and Frank F. Fowle.

CLEVELAND

The Cleveland Section made an inspection trip to the local plants of the American Steel and Wire Company on September 22, in company with a number of members of the Cleveland Engineering Society. The party met at the central furnaces and were conducted over the plant by guides. One of the most interesting features here was the new direct-connected gas engine generating station which will furnish power to the local plants. From the furnaces the entire party, of 86 members of both organizations, were taken by train to the Cuyahoga works. A luncheon was served en route. At the Cuyahoga works, which are entirely electrically driven, the party were shown the operation of rolling and finishing of flat wire, and the drawing of round wire. The Newburgh plant was next visited. At this plant both the Bessemer and open hearth processes were seen in operation on iron from the central furnaces, and also the rolling of billets and of the larger sizes of wire.

LYNN, MASS.

A preliminary meeting of the Lynn Section, for the purpose of organizing, was held on October 4, with 25 Members and Associates of the Institute present. The following officers were elected: Chairman, E. E. Boyer, secretary, I. H. Sclater. Plans were then discussed, and it was decided to call the first meeting for October 5, in order that those interested might make application for admission to membership in the Section. The dues for local members were fixed at $2.00 per annum.

The meeting of October 5 was devoted to the discussion of Section matters. Among the speakers were Messrs. W. C. Fish, of Lynn, the originator of the Lynn Section movement, W. A. Hall, of Lynn, E. A. Baldwin, of Schenectady, former chairman of the Schenectady Section, and Dr. Charles P. Steinmetz, honorary chairman of the Schenectady Section.

Mr. Fish in an interesting talk expressed the opinion that the Lynn Section might be made one of the foremost in the country.

Mr. Hall spoke of the success of Sections that had come under his personal observation, with particular reference to the Pittsfield Section, with which he had formerly been connected. This Section showed a growth of more than three times its original number in a period of less than three years.

Mr. Baldwin gave a talk on the work of the Schenectady Section. He gave figures showing the remarkable growth of that Section from 70 members when first organized, to 600 at the present time. The average attendance at meetings last year was more than 300.

Dr. Steinmetz gave a talk on the advancement of electrical engineering, in which he gave some interesting figures showing the development of the electrical field.

Those interested in the organization of the Lynn Section were very much gratified at the attendance at this meeting, there being more than 400 members and visitors present. Already 375 of that number have been enrolled as members of the Section.

MILWAUKEE

The Milwaukee Section held its opening meeting of the season of 1911–1912, in the Plankinton House, Milwaukee, on October 11, in coöperation with the

Digitized by Google

Engineers' Society of Milwaukee. Seventy-nine members and guests were present to listen to a talk on "City Efficiency and Promotion Work", by Dr. B. M. Rastell, of the Milwaukee Bureau of Efficiency and Economy. Dr. Rastell gave an outline of the conditions of civic government, covering the broad scope of the work, and dealing with the conditions which tend to low efficiency in civic work. Comment was made on the German practice of promotion of specially trained civic employes, and of the impossibility of applying that method to American conditions. To meet the need, efficiency bureaus have been established so that specially trained men may plan and advise city administrations along the different lines in which the advisors may be considered experts. Methods of analysis of several different problems were dealt with in detail, and the results obtained in a few specific instances demonstrated that similar possibilities of great improvement probably exist in other branches of civic work.

Minnesota

The members of the Minnesota Section inspected the three new stations of the Minneapolis General Electric Company, at Riverside, Main Street, and Sixth Street, on September 30. The trip was followed by an informal dinner and meeting which was held at Donaldson's Tea Rooms. Mr. Don L. Gallusha gave a talk on "The Design of the Stations", and Mr. H. J. Gille also spoke, on "The Relation of the Stations to the Service Furnished." Informal talks were also given by Dean Francis C. Shanahan, Dr. H. F. Eddy, and Professor F. W. Springer. Thirty-one members took part in the inspection and were present at the meeting.

Philadelphia

The Philadelphia Section held a joint meeting with the Electrical Section of the Franklin Institute on October 12. Mr. Walton Clark, President of the Franklin Institute, resigned the chair to Mr. H. Clyde Snook, who made the opening address relating to the work of the Philadelphia Section for the current year. Mr. Snook then introduced Major G. O. Squier, of the Signal Corps, U. S. A., who presented a paper on "Electrical Methods of Intercommunication for Military Purposes", which was illustrated by lantern slides showing the work of the signal corps. This was followed by a description of some of the research work carried on by the department, special stress being laid on the work on multiplex telephony. Messrs. Snook, Hering, Thomas, Spencer, Goodspeed and Northrup took part in the discussion.

Pittsburgh

The regular monthly meeting of the Pittsburgh Section was held in the rooms of the Engineering Society of Western Pennsylvania on October 10. In the absence of Mr. K. C. Randall, Mr. W. Edgar Reed was elected temporary chairman. A paper on "Industrial Illumination with Particular Reference to Steel Mills" was presented by Mr. C. J. Mundo. Those taking part in the discussion were Messrs. B. R. Shover, C. B. Auel, C. W. Hill, and W. Edgar Reed.

Pittsfield

One hundred and fifty-five members of the Pittsfield Section gathered at the opening meeting for this season, held on October 19, to hear an address by Dr. C. P. Steinmetz, of Schenectady, on "Unexplored Fields in Electrical Engineering." The meeting was preceded by a dinner at which Dr. Steinmetz was the guest. The address was closely followed by those present, and Dr. Steinmetz replied to a number of queries made at the close of his talk. A number of engineers from Schenectady were among those present.

San Francisco

The first meeting of the San Francisco Section for the season of 1911–1912

Digitized by Google

was held on Friday evening, September 29, in the assembly room of the Home Telephone Building, 333 Grant Avenue, San Francisco. Seventy-three members were present. A talk on Public Service Commissions " was given by Mr. Max Thelen, attorney for the California State Board of Railway Commissioners.

Owing to the continued absence of Mr. Thelen from town previously to the meeting, it was impossible for him to prepare a paper. The talk was extemporaneous, but nevertheless extremely interesting. Prior to the meeting a table d'hote dinner was served at the Old Poodle Dog Restaurant, at which about 20 members were present.

St. Louis

The first meeting of the St. Louis Section for this season was in the form of a dinner at Lippe's Restaurant, followed by a business session. Professor A. S. Langsdorf, representatives of the St. Louis Section at the Chicago Convention, gave an informal talk regarding the convention.

A joint meeting of the St. Louis Section with the Engineers' Club of St. Louis was held on October 18, in the rooms of the Engineers' Club. Mr. G. W. Lamke, chairman of the St. Louis Section, presided. Mr. John L. Carlisle, of the Moloney Electric Company, read a paper on " Comparison of Types of Transformers." A brief history of the development of transformers was given, followed by a comparison of the core and shell types, and a discussion of the construction and performance of transformers in general. The paper was illustrated by lantern slides, and the construction details were explained by reference to several types of transformers and partly finished coils loaned for the occasion by several electrical companies. The discussion that followed related mainly to the advantages of silicon steel and the impregnation of coils. Among those taking part in the discussion were Messrs. Langsdorf, Timmerman, Moloney, Waters, and Clarkson.

Seattle

The Seattle Section held its opening meeting for the season at the Arctic Club on September 16. There was a general discussion of plans for the coming year, which was followed by an informal dinner.

Toledo

The regular monthly meeting of the Toledo Section was held at the Toledo Commerce Club on Friday evening, October 6. The meeting was preceded by a dinner at which Mr. M. W. Hansen acted as toastmaster. After the dinner five minute talks were given by various members on their favorite topics. In conclusion Mr. C. B. Cook gave a talk, which was illustrated by lantern slides, on hydroelectric plants, bringing out various features of the impulse and reaction turbines, also details of the governors and nozzles used on impulse turbines.

The following afternoon, Saturday, October 7, the members made a trip to the hydroelectric plant at Miami, to which ladies were invited. Mr. Robertson, of the Miami Power Company, escorted the visitors through the plant and explained the apparatus.

Toronto

The first meeting of the Toronto Section for the season of 1911–1912 was held on October 6, in the rooms of the Engineers' Club, Toronto. Officers for the ensuing year were elected as follows: Chairman, A. L. Mudge; vice-chairman; F. A. Gaby; secretary, Valentine Boyd; Executive Committee, the chairman, vice-chairman and secretary, and Messrs. J. G. Jackson, P. H. Kemble, and D. H. McDougall. A vote of thanks was unanimously adopted and tendered to Mr. W. H. Eisenbeis, who has been secretary of the Toronto Section for several years and who has now moved to Pittsburgh. Mr. E. Richards gave an interesting account

Digitized by Google

of the Chicago Convention. A lantern slide talk was then given by Mr. Parker H. Kemble, on the construction of the Fourth Avenue subway, Brooklyn, N. Y.

URBANA, ILL.

The regular meeting of the Urbana Section was held in the electrical engineering laboratory of the University of Illinois on October 11. The following officers were elected for the current year: Chairman, E. H. Waldo; vice-chairman, T. D. Yensen; secretary, F. G. Willson; treasurer, A. Morris Buck.

WASHINGTON, D. C.

The Washington Section held its first fall meeting in the Telephone Building on October 10, with an attendance of 150 members. Section 3 of the local by-laws, relating to officers, was amended. Dr. Frank B. Jewett read a paper entitled "Telephone Transmission Engineering." A more extended report of Dr. Jewett's paper will be found elsewhere in this issue.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch resumed its activities at a preliminary meeting held on October 10 for the purpose of acquainting the new men with the Branch and its work. A historical sketch of the Institute was given by Professor W. N. Gladson, in which he discussed the object and work of the Institute and the value of membership in it. He also spoke of the work of the Branch and presented to his hearers the benefits to be derived by the student from active participation in its work. In conclusion Professor Gladson gave a brief review of the application of electricity in the various industries. Messrs. Hulse, Harrison, Moody and Lenker, seniors in electrical engineering, gave numerous experiments with the alternating magnetic field, the talking arc, and the Tesla coil.

ARMOUR INSTITUTE OF TECHNOLOGY

The first fall meeting of the Armour Institute Branch was held on September 21. The meeting being an informal one, no program had been prepared, and Chairman L. H. Roller called upon some of the members to address the society. Professor Freeman was the first to respond, and spoke briefly on the history of electrical engineering and the purpose of the A.I.E.E. Professor Clifford next gave a short talk on the importance of a good training in English. Professor Barrows spoke on the value of extemporaneous speaking. Those students who had been engaged in electrical work during the summer were asked to tell of their experiences. Messrs. Langstaff, Whitaker, Pagliarulo and Strong responded. Mr. Roller concluded with a talk on the work of the Branch for this year.

The Branch held its second meeting in Chapin Hall on October 5. Chairman Roller presided and called the meeting to order at 8:30 p.m. He then introduced Mr. C. R. Schuler, who read a paper on "Out-Door Arc Lighting." The paper explained the fundamental principles of the arc light, and described in detail the series and multiple types of lamps. It dealt also with the different kinds of arcs, such as the plain carbon, the magnetite and the flaming carbon arcs. Several additional facts were brought out in the discussion which followed.

A special and joint meeting of the Armour Institute Branch was held in coöperation with the Armour Institute Branch of the A.S.M.E. on the evening of October 11, and presided over by Chairman Roller. The speaker was Dean H. M. Raymond, who presented a paper entitled "A Few Hints to Engineering Students." Dean Raymond prefaced his remarks by the definition of an engi-

Digitized by Google

neer as " One skilled in the application of the forces and materials of nature to the uses of man." In order to become an engineer it is necessary to have a definite conception of what one wishes to accomplish. This should be followed by a thorough acquirement of knowledge by extended reading of books, technical journals and trade literature relating to the field of endeavor chosen. It is also advisable to keep note-books filled with valuable details and memoranda, including prices from which to make estimates of costs. Another requisite for the engineer is the ability patiently to persevere until satisfactory results are accomplished. It is also necessary to decide questions quickly, to work with the enthusiasm that inspires others, to be accurate in all calculations, to plan carefully for work ahead, and to save systematically in order to have capital when it may be necessary.

University of Colorado

The University of Colorado Branch held its regular meeting on September 20, with Chairman L. R. Leonard presiding, and a total attendance of 34 members. Professor H. S. Evans spoke of the A. I. E. E. and the local Branch. Professor D. R. Jenkins commented on the excellent work of the society in previous years and encouraged his hearers to work for its success during the coming year.

The next meeting of the Branch was held on October 4. Messrs. W. Trudgian and W. H. Bullock, both of whom are now in the Denver office of the Westinghouse Electric and Manufacturing Company, gave an illustrated lecture on " Outdoor High Tension Construction." Some excellent lantern slides added greatly to the interest and value of the lecture.

University of Kansas

This Branch held its first fall meeting on September 27, with 47 members present. Mr. A. W. Weibel, of the U. S. Bureau of Standards at Washington, D. C., presented a paper on " Measuring and Standardizing of Resistances." Professor George C. Shaad gave a talk on the A. I. E. E. and its relation to the work of the Branch.

The Branch held its next meeting on October 11. Mr. M. K. Thomas gave a review of current electrical literature, speaking at some length of the electrification of the Hoosac tunnel. Dr. E. W. Tillotson gave a talk on " The Scientific Design of Reflectors." Dr. Tillotson is with the Holophane Company and is now working on the problem of how to give color to the light from the Cooper-Hewitt mercury vapor lamp.

Lehigh University, South Bethlehem, Pa.

The October meeting of the Lehigh University Branch was held on Tuesday evening, October 10. Fifty-nine members were present to hear and discuss the papers presented. The first paper on the program was by Mr. A. G. Birdsall, '12, on " Alternating Current and Direct Current Transmission Lines ", in which he dealt very clearly and thoroughly with the different phases of transmission work. Mr. C. E. Clewell, illuminating engineer of the Westinghouse Electric and Manufacturing Company, read the second paper, on " Illuminating Engineering ", giving a history of illumination and its development to the present time.

University of Missouri

The University of Missouri Branch held its opening fall meeting on October 2. There was some discussion as to means of making meetings more interesting and valuable, and the following general policy was decided upon. Any article of interest to electrical engineers, appearing in any publication whatsoever, or any subject of interest, was to be considered proper material for discussion at the Branch meetings. The presentation of highly technical

Digitized by Google

papers which would be likely to prove unintelligible or uninteresting to a large number of the students present was to be discouraged. The executive committee was authorized to call upon men to take part in the discussion following the presentation of any paper, and to notify them in advance that they would be expected to take part. The chairman was authorized to call upon any members to assist the committee in looking over current literature for good material. The Branch as a whole was also to take it upon itself to assist the committee by calling its attention to good material for discussion and making suggestions. The idea of increasing the information of students was to be secondary to that of developing self confidence and the ability to express their ideas. Following the business session Mr. F. P. Huston gave an informal talk in which he told of some of his experiences in connection with his work for the Colorado Fuel and Iron Company.

Montana State College

The annual election of the Montana State College Branch was held on October 11, and the following officers were elected: Chairman, J. Glen Luther; secretary, J. A. Thaler. The newly elected officers were called upon to speak and gave brief talks on the work and scope of the Branch and the benefits to be derived from membership therein.

Purdue University

The Purdue University Branch held its first meeting for the year on Tuesday evening, October 10. At this meeting the ideals and purposes and policy of the Purdue Branch, and the proposed program for the year's work were discussed by Professors Harding and Topping.

Stanford University

The Stanford University Branch resumed its activities at a meeting held on September 22, with Mr. S. B. Shaw presiding, and an attendance of 21 members. Several minor business matters were discussed, and the treasurer submitted his report, after which a paper on "High Tension Testing of Insulating Materials" was read by Mr. R. G. Marx. This was followed with one on "Storage Batteries" by Mr. H. E. Pelton.

Throop Polytechnic Institute, Pasadena, Cal.

A meeting of the Throop Polytechnic Institute Branch, marking the opening of the season, was held on October 6. Three papers were presented; two on the Southern California Edison Company's steam electric plant at Long Beach, Cal., by Messrs. H. S. Wood and A. W. Wells, and the other on the Pacific Light and Power Company's conduit system in Los Angeles, Cal., by Mr. H. B. Gurckens. At the close of the discussion of the papers Mr. R. W. Sorensen gave a talk on the work of the Branch and plans for the year.

Worcester Polytechnic Institute

Dr. Clarence A. Pierce, assistant professor of electrical engineering at the Worcester Polytechnic Institute, addressed the Branch at a meeting held on October 13, on "Accuracy in the Determination of Electrical Quantities." Dr. Pierce gave a brief history of the development of standard measures in general and then took up the development and standardization of the more common electrical quantities; volt, ampere, and ohm. He spoke at some length on the growth and importance of the National Bureau of Standards, giving several instances where important disputes had been quickly settled by the Bureau. The meeting then adjourned to the standards laboratory, where considerable time was spent in examination and discussion of the various standards which are kept there for calibrating the laboratory instruments.

Digitized by Google

Personal

MR. ALFRED MULLHAUPT, JR., has resigned his position with the Buffalo Forge Company to enter the sales department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

MR. E. W. NICK has resigned his position with the Isthmian Canal Commission at Gatun, C. Z., and is now pursuing graduate work at the Harvard Graduate School of Business Administration.

MR. WILLIAM C. GETZ, Signal Service at Large, U. S. A., has left Chicago, Ill., for Manila, P. I., where he will take charge of the construction of wireless telegraph stations and apparatus in the Philippine Division.

MR. R. M. OSTERMANN has left the General Electric Company, with whose foreign department he has been connected for the last five years, to become assistant to the vice-president of the Superheater Company, with headquarters in Chicago.

MR. E. A. GRAHAM, until recently with the Canadian Westinghouse Company on the erection of station apparatus for the hydroelectric plant for the City of Winnipeg, has been appointed assistant electrical engineer for the Winnipeg Electric Railway Company.

MR. A. H. KROM, formerly with the Commonwealth Edison Company, as commercial and illuminating engineer, is now with the Haskins Glass Company of Wheeling, W. Va., and will have charge of the illuminating engineering and sales of the company's Chicago, Ill., branch.

MR. W. C. WAGNER, electrical and mechanical engineer of the Northwestern Improvement Company, has accepted a chair in the department of electrical engineering of the University of Washington, for the coming year, substituting for Dr. C. E. Magnusson, who is absent on leave.

MR. R. MEINIG has resigned as general electrical designer with the Jones and Laughlin Steel Company, Woodlawn, Pa., to become general electrical designer and electrical engineer for the Pittsburgh Crucible Steel Company, Pittsburgh, Pa. Mr. Meinig's address is 3339 Milwaukee Street, Pittsburgh, Pa.

MR. JENS BACHE-WIIG, engineer, with the Westinghouse Electric and Manufacturing Company, in charge of alternating-current generator and rotary converter design, has been appointed by the Norwegian government professor of electrical engineering at the Norwegian Technical University in Trondhjem, Norway, to take effect on January 1, 1912.

MR. J. F. STEVENS resigned on July 1 the presidency of the Keystone Electrical Instrument Company, of Philadelphia, and sold all of his interest therein. Mr. Stevens established the Keystone Electrical Instrument Company in 1893, and continued in charge of it until July 1, 1911. Mr. Stevens expects to devote his time and attention to consulting electrical engineering and has established offices at 702 Hale Building, 1326 Chestnut Street, Philadelphia.

Obituary

MR. EVERETT COPLEY, of the New York sales office of the Westinghouse Electric and Manufacturing Company, died at his home in New York on Thursday, September 27, 1911, after an operation for appendicitis followed by an attack of typhoid fever.

Mr. Copley was born in Kansas City, Mo., on June 24, 1886. He graduated from the Central High School in 1904, and from the University of Kansas in 1906, having won a scholarship which gained him membership in the Phi Beta Kappa Society. Upon leaving

Digitized by Google

the university he entered the employ of the Westinghouse Electric and Manufacturing Company, and was first engaged on the electrification of the New York, New Haven and Hartford Railroad. About three years ago he entered the New York sales office of the Westinghouse Company, where he achieved a marked success as engineer salesman. Mr. Copley was a member of the Crescent Athletic Club of Brooklyn, N. Y., and an Associate of the American Institute of Electrical Engineers. He became an Associate on May 17, 1910. His body was taken to Kansas City for burial.

MR. OTIS CARTER POST, of the switchboard sales department of the Westinghouse Electric and Manufacturing Company, died suddenly of cerebral embolysm at his residence in Wilkinsburg, Pa., on Wednesday night, September 13, 1911.

Mr. Post was born in Lowell, Kent County, Michigan, on November 10, 1883. He was graduated with the degree of bachelor of science from the Michigan Agricultural College in 1907. In June of the same year he entered the employ of the Westinghouse Electric and Manufacturing Company as an apprentice, and rapidly rose to a position of importance in the sales department. Mr. Post was widely known among the employes of the Westinghouse Company, as well as outside, and was universally respected for his qualities of sound judgment and tact. He has just returned from an extensive trip in the East, in the interest of the company. Mr. Post was president of the Pittsburgh Alumni Society of the Tau Beta Pi Fraternity, and a member of the masonic order at Lowell, Michigan. He was elected an Associate of the Institute on May 19, 1908.

MR. EVERET GRANT TRACY, of Andover, N. Y., died at the General Hospital at Wellsville, N. Y., on Friday, September 8, 1911. Mr. Tracy was born in Richburg, N. Y., on August 3, 1884. When he was 12 years of age his parents moved to Andover, where his boyhood and school days were passed. He graduated from the Andover High School in 1902, and from the Clarkson School of Technology at Potsdam in 1908. He then went to Pittsfield, Mass., and entered the employ of the General Electric Company. The following year he was transferred to the Schenectady works, where he remained until a little less than two years ago, when failing health caused him to resign his position and return to his home in Andover. It was thought by his family that a period of rest would restore him to strength, but his condition became worse and tuberculosis soon developed. Mr. Tracy was a mason, and an Associate of the Institute, having been admitted to membership in the latter on March 11, 1910. He is survived by his father, Mr. Charles Tracy, and one brother, Carl Tracy, of Fletcher, Canada.

MR. FRANK T. CLARKE, of the Hammel Oil Burner Company, Los Angeles, Cal., was killed in an automobile accident in Honolulu, Hawaii, early in the summer. Mr. Clarke was born in Philadelphia, Pa., on April 12, 1882. He received his preliminary education in Chicago, graduating from a grammar school in that city, after which he spent four years in the study of mathematics and general engineering subjects at the Chicago Nautical School. He also took the course in electrical engineering, of the International Correspondence Schools. His first position was with Frazer and Chalmers, of Chicago, as machinist's helper and erector. Subsequently he held positions with various concerns as dynamo tender, marine engineer, engineer, inspecting engineer, and instructor in marine engineering at the Chicago Nautical School. Early in 1909 he went to the Pacific coast and entered the employ of the Pacific Light and Power Company. On October 1, 1910 he became

Digitized by Google

a partner in the Hammel Oil Burner Company. He was elected an Associate of the Institute on August 14, 1908.

MR. EVERETT B. BOOR, of the testing department of the General Electric Company, Schenectady, died suddenly on May 18 last, from acute appendicitis. Mr. Boor was born in New Castle, Ind., on June 7, 1884. He graduated from the Muncie, Ind., High School in 1902, and from the electrical engineering department of Purdue University in 1908. In 1907 he entered the employ of the Muncie Electric Light Company. He became associated with the General Electric Company in January, 1910. Mr. Boor was admitted to membership in the Institute as an Associate on April 15, 1910.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Arbeiten aus dem Elektrotechnischen Institut der Grossherzoglichen Technischen Hochscule Fridericiana zu Karlsruhe, 1908–1909. By E. Arnold Berlin, 1909. (Purchase.)

——II Band, 1910–1911. By E. Arnold Berlin, 1911. (Purchase.)

Bekanntmachung : ber Pr fungen und Beglaubigungen durch die Elektrischen Prüfamter. Nos. 1–10, 12–18, 20–32, 34–45, 37–50. N.p. n.d. (Purchase.)

——Register zu Nos. 1–46. Berlin, 1910. (Purchase.)

Electric Traction for Railway Trains. By E. P. Burch. New York, McGraw Hill Book Co., 1911. (Purchase.)

Die Entwickelung der Grossen Berliner Strassenbahn und ihre Bedeutung fur die Verkehrsentwickelung Berlins. By Edward Buchmann. Berlin, 1910. (Purchase.)

Generation and distribution of electricity with special reference to lighting. By J. B. Whitehead. (Two lectures delivered at the Johns Hopkins University, Oct.–Nov., 1910). N.p. n.d. (Gift of author.)

High Voltage Corona in Air. By J. P. Whitehead. (Reprinted from Proceedings of the American Philosophical Society, Vol. 50, 1911.) N.p. n.d. (Gift of author.)

National Electrical Code. Rules and requirements of the National Board of Fire Underwriters for Electric Wiring and Apparatus. 1911. N.p. 1911. (Exchange.)

New York City Department of Docks and Ferries. Studies for combined waterfront and terminal industrial development applicable to frontage on different parts of New York Harbor. By C. Tomkins. August 1, 1911. N.p. n.d. (Gift of C. W. Staniford.)

Ohio Northern University. Annual Catalogue 1910–12. Ada, 1911. (Gift of University.)

Parisher Stadtbahn. By Ludwig Troske, Berlin, 1905. (Purchase.)

Praktische Anleitung zur Herstellung einfacher Gebaude Blitzableiter. Ed. 2. By F. Findeisen. Berlin, 1907. (Purchase.)

Die Preisstellung beim Verkaufe Elektrischer Energie. By Gustav Sigel. Berlin, 1906. (Purchase.)

Radio-activity. A brief guide to its use in general and specialist practice. By G. Stephen, London, 1910. (Gift of Messrs. Siemens & Halske).

Rubber, production and utilization of the raw product. By C. Beadle and H. P. Stevens, London, n.d. (Purchase.)

Svenska Teknologföreningen. Ledamotsförteckning jamte Stadgar och Ordningsregler July, 1911. Stockholm, 1911. (Gift of Svenska Teknologföreningen.)

Die Wechselstromtechnik. Band V–pt. 1. By E. Arnold. Berlin, 1909. (Purchase.)

Trade Catalogues

Allgemeine Elektricitats Gesellsch. Berlin. Electric arc light welding appliances. 11 pp.

Digitized by Google

Duncan Electric Mfg. Co., Lafayette, Ind. Bull. No. 20—Duncan direct current watthour meter. 24 pp.

Emerson Electric Mfg. Co., St. Louis, Mo. Bull. No. 3144—Single phase induction motor 1/10 to 1/5. 4 pp.

——Bull. No. 3220—Ventilated motors for direct current. 8 pp.

——Bull. No. 3710—Laboratory lathes. 8 pp.

Fort Wayne Electric Works, Fort Wayne, Ind., Bull. No. 1130—Northern Type K Direct Current Motors. 15 pp.

——Bull. No. 1131—Series Incandescent Street Lighting Systems. 23 pp.

——Bull. No. 1132—Multiphase Revolving Armature Alternators. 7 pp.

——Bull. No. 1133—Single Phase Watt-Hour Meters. 7 pp.

General Electric Co., Schenectady, N. Y. Index to bulletins. 8 pp.

——Bull. No. 4835—Electrically Driven Pumps. 18 pp.

——Bull. No. 4836—G. E. Steam Flow Meter. 16 pp.

——Bull. No. 4845—Curtis Steam Turbine Generators of 100–1000 Kw. Capacity at 3600 Rev. Per Min. 15 pp.

——Bull. No. 4846—A.C. Switchboard Panels. 18 pp.

——Bull. No. 4847—Belt Driven Alternators, Form B. 5 pp.

——Bull. No.4848—Automobile Instruments. 3 pp.

——Bull. No. 4849—Motor-Generator Sets. 19 pp.

——Bull. No. 4850—Edison Mazda Lamps. 26 pp.

——Bull. No. 4851—Electricity in the Service of Steam Railroads. 47 pp.

——Bull. No. 4852—50 Ton Electric Locomotives. 11 pp.

——Bull. No. 4853—Electric Arc Headlights. 14 pp.

——Bull. No. 4855—The Gas-Electric Motor Car. 29 pp.

——Bull. No. 4856—U. S. 13 Roller Bearing Trolley Bases. 3 pp.

——4 Stereofotos of Electrical Instruments. 4 pp.

——Bull. No. 4858—Single phase motors, type RI. 15 pp.

——Bull. No. 4863—Metallized Filament Lamp. 9 pp.

——Bull. No. 4864—Hand-operated starting compensators for a.c. motors. 13 pp.

——Bull. No. 4865—Electric hoists. 11 pp.

——Bull. No. 4866—Thomson Horizontal Edgewise Instruments for Switchboard Service. 15 pp.

——Bull. No. 4867—Electric Locomotives of 25 Ton Type. 15 pp.

——Bull. No. 4868—Rotary converters. 31 pp.

——Bull. No. 4870—100 Ton Electric Locomotives. 18 pp.

——Bull. No. 4872—Transformer, Oil Dryer and Purifier. 9 pp.

——Bulls. 4837–4842—Infolder of Circuit Breakers of Various Types. 147 pp.

Marburg Bros., New York. High Tension Magnetos. 31 pp.

Minerallac Electric Co., Chicago, Ill. Bull. No.30—Minerallac Insulating Compound. 8 pp.

——Bull. No. 35—Minerallac Cable and Conduit Hangers. 4 pp.

——Bull. No. 40—Electroscopes for Indicating Dangerous Potentials. 4 pp.

——Bull. No. 45—Printing Attachment for Integrating Meters. 8 pp.

——Bull. No. 52—Cable Joints on Underground High Tension Lines. 7 pp.

Phillips Mfg. Co., New York. Automatic Commutator Grinder. 11 pp.

Rochester Chamber of Commerce, Rochester, N.Y. The Prevention of Fire. 16 pp.

United States Electric Co., New York. Bull. No. 101—Gill selectors for telegraph service. 18 pp.

——Bull. No. 301—Vacuum lightning arresters. 14 pp.

Wagner Electric Co., St. Louis, Mo. Bull. 93—Alternating current rectifier. 7 pp.

Digitized by Google

Western Electric Co., New York. Price list of Western-Electric supplies, applying on 1908 and 1909 catalogue. 117 pp.

Westinghouse Electric & Mfg. Co., Pittsburg. Circular 1104—Portable meters for a.c. and d.c. 31 pp.

Western Electric Co., Hawthorne, N. Y. Bull. No. 1105—Various Interphone Systems. 35 pp.

UNITED ENGINEERING SOCIETY

American Year Book, 1910. New York–London, 1911. (Gift of Engineers' Club.)

Decimal Classification and Relative Index. Ed. 7, 1911. By M. Dewey. Lake Placid Club, N. Y., 1911. (Purchase.)

Graphite as a Lubricant. Ed. 11. Jersey City, 1909. (Gift of Joseph Dixon Crucible Co.)

International Institute of Technical Bibliography. Year Book (engineering Abstracts), 1910. London, 1910. (Purchase.)

Moody's Manual of Railroads and Corporation Securities. 12th Annual Number, 1911. New York, 1911. (Purchase.)

Oklahoma Geological Survey Bulletin No. 3. Norman, 1910. (Gift of Oklahoma Geological Survey.)

Rhodesia Chamber of Mines. Annual Report 16th, 1910. Cape Town, 1911. (Gift of Rhodesia Chamber of Mines.)

GIFT OF G. H. CONDICT.

American Institute of Electrical Engineers. TRANSACTIONS, Vols. 22–23, New York, 1904, 1905.

Barber, T. W. Engineer's Sketch Book of Mechanical Movements, etc. Ed. 3. London, 1897.

Camp, W. M. Notes on Track construction and maintenance. Ed. 2, Chicago, 1904.

Crosby, O. T. & Bell, Louis. Electric railway in theory and practice. Ed. 2. New York, 1893.

Hiscox, G. D. Gas, Gasoline and Oil Vapor Engines. Ed. 2, New York, 1898.

——Mechanical Movements, powers, Devices and Appliances. New York, 1899.

Jenkins, Rhys. Motor Cars and the Application of Mechanical Power to Road Vehicles. London, 1902.

Hasluck, P. N. Automobile, its Construction and Management. Translated from G. Lavergne's "Manual Theoretique et Pratique de L' Automobile sur Route" Philadelphia, 1902.

Steinmetz, C. P. General Lectures on Electrical Engineering. Schenectady, 1908.

GIFT OF UNIVERSAL VANADIUM COMPANY

Alloy Steels for Motor Car Construction. By J. A. Mathews. Pittsburgh, n.d.

Case Hardening Process. By J. K. Smith. Pittsburgh, n.d.

Estimation of Vanadium in Ferro Alloys, Steels, Cupro-Vanadium Brasses and Bronzes. Pittsburgh, n.d.

Static and Dynamic Properties of Steels. (Reprint of an article from "Iron Age" July 2, 1908). Pittsburgh, n.d.)

Vanadium: Its Application to Cast and Malleable Iron, with Results of Tests. N.p. n.d.

Vanadium: Its Service in Automobile Manufacture. By J. K. Smith. Pittsburgh, n.d.

Vanadium Spring Steel (Type "D"). Pittsburgh, n.d.

Vanadium Steels. Their Classification and Heat Treatment with Directions for Application of Vanadium to Iron and Steel. Pittsburgh, 1911.

Vanadium Steels for the Automobile. Pittsburgh, 1911.

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL. DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **ACTING SECRETARY.**

GEORGE A. HAMILTON. F. L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD,1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH WAINWRIGHT POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

HORACE FIELD PARSHALL,
Salisbury House, London Wall, E. C., London.

L.A. HERDT, McGill University, Montreal, Que.

WILLIAM G. T. GOODMAN,
Adelaide, South Australia.

ROBERT JULIAN SCOTT,
Christ Church, New Zealand.

HENRY GRAFTIO, St. Petersburg, Russia.

Digitized by Google

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
F. L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
ALEXANDER S. LANGSDORF, St. Louis, Mo.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

STANDARDS COMMITTEE.

ARTHUR E. KENNELLY, Chairman.
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Secretary.
Harvard University, Cambridge, Mass.
(Complete committee to be announced later.)

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
FRED S. HUNTING, Fort Wayne, Ind.
HENRY G. STOTT, New York.

Digitized by Google

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman, 165 Broadway, New York.
EDWIN BRITTON KATTE, Vice-Chairman, New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
GEORGE GIBBS, New York.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

ALEXANDER S. LANGSDORF, Chairman, Washington University, St. Louis, Mo.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
JOHN PRICE JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman, General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman, 139 Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill.
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman, 600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman, Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio.
ROBERT BELDEN TREAT, Ampere, N. J.
R. TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York.

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman, Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman, 43 Exchange Place, New York.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.
PHILIP TORCHIO, New York.

PUBLIC POLICY COMMITTEE.

HENRY G. STOTT, Chairman, 600 West 59th St., New York.
HAROLD W. BUCK, New York.
JOHN J. CARTY, New York.
JOHN H. FINNEY, Washington, D. C.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman, 2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman, 29 West 39th St., New York
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman, 52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President. 90 West St., New York.
ARTHUR E. KENNELLY, Secretary, Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Cambridge, Mass.
LOUIS BELL, Boston, Mass.
JOHN J. CARTY, New York.
GANO DUNN (ex-officio), New York.
CARL HERING, Philadelphia, Pa.
JOHN W. HOWELL, Newark, N. J.
JOHN W. LIEB, Jr., New York.
RALPH D. MERSHON, New York.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
SAMUEL W. STRATTON, Washington, D. C.

CODE OF ETHICS COMMITTEE.

GEORGE FRANCIS SEVER, Chairman, 13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.

FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913

COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.

WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.

LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, New York.

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.

GANO DUNN, President, Ampere, N. J.
F. L. HUTCHINSON, Acting Secretary.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New York.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, Pittsburgh, Pa.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	H. P. Wood.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	William L. Hooper.	G. A. Rodenbaeck, 84 State St , Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	O. H. Ensign	E R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn.....Aug. 22, '11	E. E Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	K. C. Randall.	E. L Farrar, G E Co., Oliver Bldg , Pittsburgh, Pa
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. B. Charters.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. B. Merriam.	. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, Wagner Electric Mfg. Co., St. Louis, Mo.
Toledo.....June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto.....Sept. 30, '03	A. L. Mudge.	Vale tine Boy , 212 King St , West, Toronto, Ont.
Urbana.....Nov. 25, '02	E. H. Waldo.	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11		
Washington, D C..Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 27.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas.....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland.....Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio
Cincinnati, Univ. of..Apr. 10, '08		
Colorado State Agricultural College.....Feb. 11, '10	D. E. Byerley	A A Catlin, 626 So Meldrum St., Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College. .Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B. F. Hillebrandt	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	W. H. Jae le.	J. H. Gaiser, 341 Harrison Ave., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute. .....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J. Glen Luther.	J. A .Thaler, Montana State College, Bozeman, Mont
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll ....Oct. 13, '11		
Oregon State Agr. Col Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of ....Nov. 11, '10	R H. Dearborn	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan 26. '03	C. F. Harding.	A. L. Topping, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Polv. Institute, Troy, N. Y.
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N Y.
Texas, Univ. of.....Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, Cal 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Polv. Inst Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.
Yale University.....Oct. 13, '11		

Total 8

Digitized by Google

CONTENTS OF SECTION II

Papers, Discussions and Reports

Discussion on "Automatic Motor Control for Direct Current Motors," Chicago, June 28, 1911 - - - - - - - - 2221

Discussion on "Electrically Driven Reversing Rolling Mills," Chicago, June 28, 1911 - - - - - - - - 2229

Discussion on "The Application of Current Transformers to Three-Phase Circuits," Chicago, June 30, 1911 - - - - - 2240

Discussion on "Cost of Transformer Losses," Chicago, June 30, 1911 - 2240

Discussion on "Electrolytic Corrosion in Reinforced Concrete," Chicago, June 30, 1911 - - - - - - - - - 2248

Discussion on "Solution to Problems in Sags and Spans," Chicago, June 30, 1911 - - - - - - - - - 2270

Discussion on "Sag Calculations for Suspended Wires," Chicago, June 30, 1911 - - - - - - - - - 2270

Discussion on "Mechanical and Electrical Characteristics of Transmission Lines," Chicago, June 30, 1911 - - - - - - 2270

Discussion on "Electric Line Oscillations," Chicago, June 29, 1911 - 2293

Discussion on "Transmission Applied to Irrigation," Los Angeles, Cal., April 25, 1911 - - - - - - - - - 2299

Discussion on "Transmission Systems from the Operating Standpoint," Los Angeles, Cal., April 25, 1911 - - - - - 2299

Discussion on "A Power Diagram Indicator for High Tension Circuits," Los Angeles, Cal., April 27, 1911 - - - - - - 2313

Discussion on "Tentative Scheme of Organization and Administration of a State University," Chicago, June 30, 1911 - - - - 2319

Discussion on "Electric Strength of Air II," Chicago, June 29, 1911 - 2333

Discussion on "The Law of Corona and Dielectric Strength of Air," Chicago, June 29, 1911 - - - - - - - - - 2333

Discussion on "The Responsibilities of Electrical Engineers in Making Appraisals," Chicago, June 27, 1911 - - - - - 2356

Discussion on "Depreciation as Related to Electrical Properties," Chicago, June 27, 1911 - - - - - - - - - 2356

Discussion on "Wave Shape of Currents in an Individual Rotor Conductor of a Single-Phase Induction Motor," Chicago, June 30, 1911 - - 2403

Discussion on "Multiplex Telephony and Telegraphy by means of Electric Waves Guided by Wires," Chicago, June 28, 1911 - - - - 2407

The Cost of Arc Lighting and General Service from Medium and Small Size Municipal or Private Plants. By W. Edgar Reed, Pittsburg, Pa., May 9, 1911 - - - - - - - - - - 2423

Turin Meeting of the International Electrotechnical Commission September 7-13, 1911 - - - - - - - - - 2437

The International Electrotechnical Congress of Turin - - - 2449

Digitized by Google

Digitized by Google

DISCUSSION ON "AUTOMATIC MOTOR CONTROL FOR DIRECT-CURRENT MOTORS." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR JULY, 1911.)

(Subject to final revision for the Transactions.)

E. J. Murphy: I have listened with pleasure to Mr. Eastwood's able presentation, and can truly say that it represents a very great step towards the ideal which designers of control apparatus have been striving to attain, namely, an automatic motor control in which complicated wiring and numerous interlocks and relays have to a great extent been eliminated. It has been my privilege to work along these lines in which a contactor actuated by a series coil also contains the characteristic of a current limit relay. The illustrations shown and described herewith represent a type of contactor which was developed to meet steel mill operating conditions; in so doing it was decided to embody the best features of the shunt wound contactors which have proven so satisfactory after many years of the most exacting service; the most important feature being the reduction of the number of contact surfaces to a minimum, the use of a solid and easily replaceable rolling contact with vertical contact faces insuring against trouble due to the accumulation of dust or dirt upon them. The above consideration led to the adoption of a pivoted armature member which possessed the further advantage of operating with a minimum of friction, which is highly advantageous in obtaining a close and uniform adjustment. This arrangement of contacts also makes possible, when equipped with blow-out coils, the disrupting of heavy currents which is advantageous in certain applications of motor control. I wish to say, however, that this series contactor when used in an ordinary starting or reversing equipment is not called upon to open any appreciable current, making magnetic blow-out coils unnecessary. Your attention is particularly drawn to a very simple and effective method of connection, which makes it imperative that the contactors close in proper sequence, only one contactor being closed at a time. It should also be noted when the last contactor goes in, the other accelerating contactors are open while the motor is running. The above condition is brought about by means of the series coils only, no extra fine wire windings being necessary. This arrangement operates perfectly on a quick reversing equipment without any additional interlocking coils for delaying the action of the reversing line contactor.

Fig. 1 shows the contactor with the switch in the open position. C is a series wound actuating coil with a vertical iron core which projects through the brass supporting block B, and forms a pole face adapted to attract the cast iron armature A, across the upper air gap G_1. This armature is pivoted at P and carries the moving contact T, also the vertical iron strip L. The lower end of L forms a pole face which is attracted across the lower air gap G_2 by the horizontal iron extension E at the bottom of coil C. The armature A and the strip L form a bell crank lever: the at-

Digitized by Google

traction at the upper gap G_1 tends to close the switch and the attraction at the lower gap G_2 tends to hold the switch in the open position. The brass nut N, provided with locking spring, forms a stop for the strip L, thus regulating the length of the lower air gap G_2. This adjustment determines the current value at which the switch will close. (A more satisfactory adjusting device is shown in Fig. 2.) A vertical iron strip S of limited cross section connects the horizontal projection E and the iron casting to which the moving element is pivoted at P. This strip S forms a magnetic shunt to the lower air gap G_2, thus providing an alternative path for the magnetic flux.

The path of the magnetic flux is as follows: starting from the

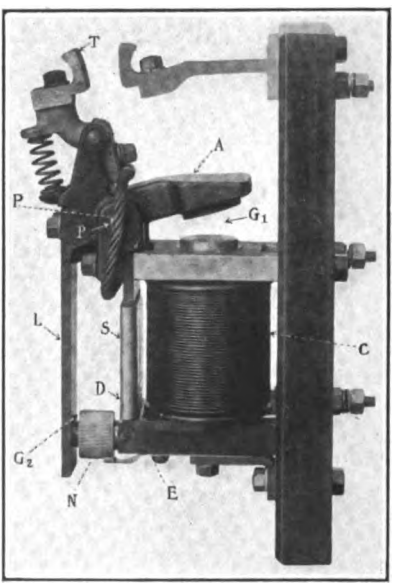


FIG. 1

upper end of the core in coil C, across the gap G_1, along the armature A, to the pivot P where the flux divides, one portion flowing down the strip L, across the gap to the projection E. Another portion flows down the iron shunt S to the projection E. The total flux then flows along E to the magnet core of coil.

When current is switched through the coil C and this current is higher than the closing value for which the device is adjusted, the attraction across the lower gap G_2 is sufficient to hold the switch open against the attraction across the upper gap G_1. When the current falls, due to the acceleration of the motor, the magnetic flux in all parts of the magnetic circuit will decrease. The permeability of the iron shunt S will therefore increase, and

Digitized by Google

in consequence, will carry a larger proportion of the flux relative to the lower gap G_2; these parts of the magnetic circuit being in parallel. The attraction across the lower gap G_2 will fall at a greater rate than the decrease in the attraction at the upper gap G_1, and finally, when the current arrives at the adjusted closing value, the attraction at the lower gap G_2 can no longer hold the moving element and the switch will close.

There was one serious difficulty which had to be overcome in the design, *i.e.*, to make certain that the contactor would hold open when the first rush of current through a highly inductive circuit was very little above the value at which the device was

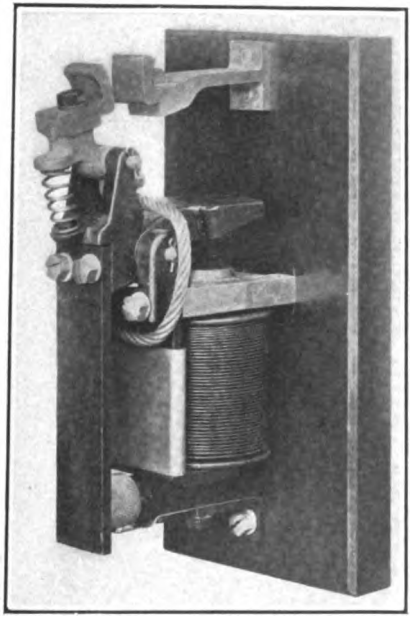
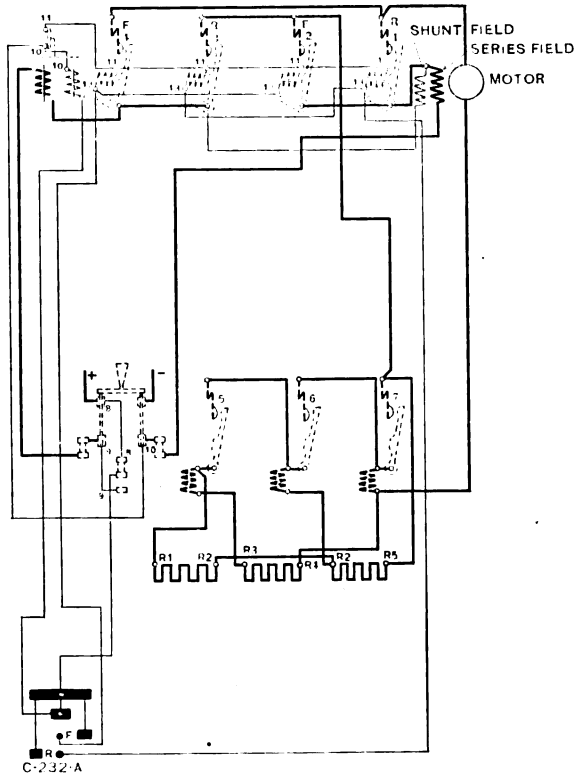


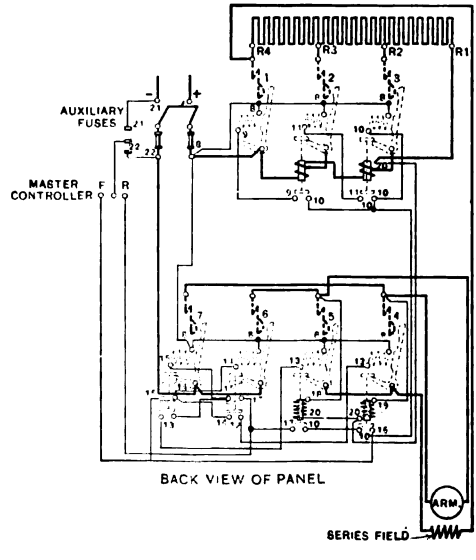
FIG. 2

set to trip. This problem was solved by encircling the iron shunt S with a low resistance copper band D. The rapid rise in the flux value in the shunt S when the current is first switched on, generates a momentary heavy current in the copper band which opposes the increase of the flux. This action causes a larger proportion of flux to be forced across the gap G_2 while the current rising, thereby increasing the attraction at the point until the current has risen to a safe value. In quick reversing equipments, the adoption of a longer copper band as shown in Fig. 2, rendered unnecessary the use of complicated interlocking devices.

Digitized by Google



MECHANICAL INTERLOCK
BETWEEN CONTACTORS LAND 2, 3 AND 4
BACK VIEW OF PANEL



BACK VIEW OF PANEL

MECHANICAL INTERLOCKS BETWEEN 4 AND 5, 6 AND 7

FIG. 3

Digitized by Google

The flexible connection for carrying the current around the pivot presented another serious problem, inasmuch as the mechanical forces due to the stiffness or " spring " of such connection might interfere with the adjustment of the device. The arrangement shown in Fig. 2 effectually solves the problem. The connection consists of a loop of flexible cable of many fine copper wire strands. The plane of the loop is parallel to the axis of the pivot, and the axis lies in this plane. Any force due to the tendency of the loop to open or close, will be exerted, radially across

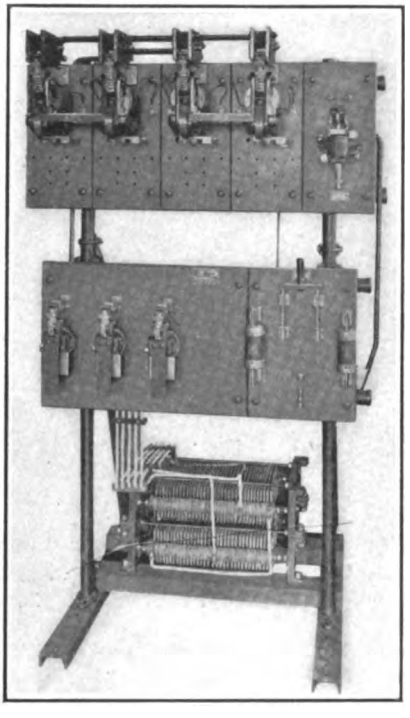


FIG. 4

the pivot, with no torque around the pivot. Actual tests proved the accuracy of the above assumption.

In connection with the subject of series wound contactors in general, I note that Mr. Eastwood did not bring out one very important advantage, *i.e.*, the use of coil windings of few turns and large cross section of conductor. The construction shown, in Fig. 2 is typical; the coil consisting of relatively few turns of bare edgewise wound copper strip with one end connected to the frame. This construction will stand very heavy overloads without damage. The potential strain across the coil and from coil to spool is only a fraction of a volt.

Digitized by Google

Fig. 2 also shows an improved adjustment for the lower gap G_2. The lower end of the vertical strip L abuts against the head of a fixed brass stud which supports an iron thimble. This thimble can be screwed along the stud, thereby controlling the width of the air gap G_2. Simple and positive locking devices are provided.

Fig. 3 shows the contrast between two connection diagrams

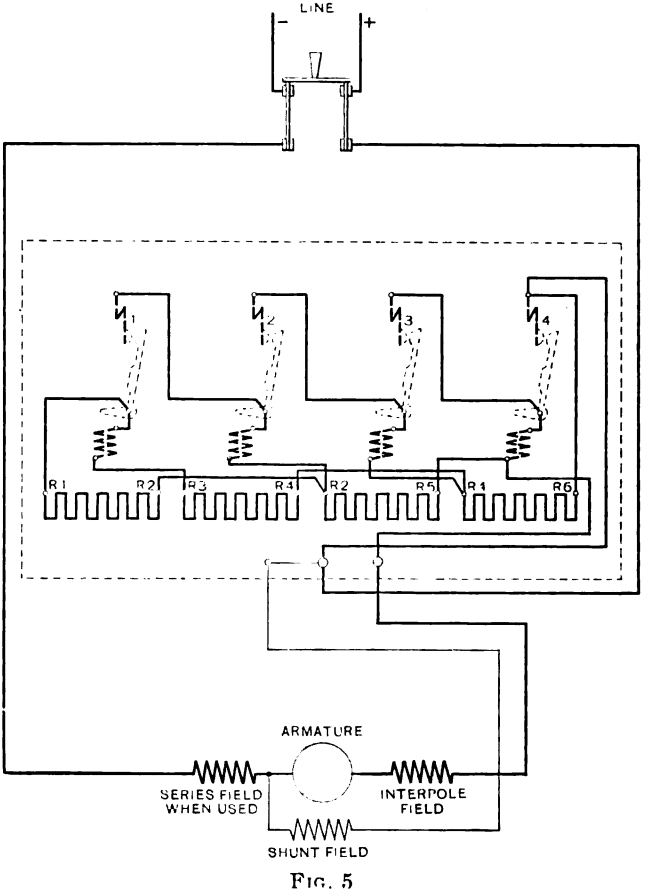


FIG. 5

for starting and reversing a direct current motor. The right-hand diagram shows the old fashioned arrangement with current limit relays operating shunt wound contactors with numerous electrical interlocks. The left-hand diagram shows the series contactor accelerating arrangement for the same duty, no electrical interlocks being required.

Fig. 4 shows the front view of a starting and reversing panel

Digitized by Google

using series accelerating contactors designed for heavy steel mill duty and Fig. 5 shows a wiring diagram of a very simple motor starting panel, using four series wound accelerating contactors with hand operated line switch and fuses.

Arthur C. Eastwood: As to the matter of contacts, brought up by Mr. Murphy, it must be remembered that this switch acts not only as a switch, but also as a relay. Whether the switch is a small one wound say for a one-horse-power motor, or a large one wound say for a 1,000-h.p. motor, when the current through the winding of the switch is reduced to a certain critical value the weight of the moving parts is just balanced by the magnetic pull. This is the sensitive point in the operation of the switch, and at this point the reliability of its action may be seriously disturbed by the friction of a pivot and by the variable action of the shunt which is essential in carrying current around the pivot in a switch of the single-break pivoted-arm type.

Experiments with switches of the pivoted-arm type did not give reliable results within prescribed limits of accuracy, and led to the adoption of the construction illustrated in my paper. In this construction there are no pivots, pins, or shunts. The plunger of the switch is mounted vertically, and the magnetic pull tending to close the switch acts against gravity, which is as nearly constant as anything we know of.

As to the matter of interlocks for reversing controllers, notwithstanding the fact that the series wound switch is very quick in action, in very rapid reversing service there is danger of the reverser being thrown before all of the resistance switches have opened. An interlock which will prevent this appears to be a safety precaution which is well warranted, particularly in controllers for reversing mill tables. Such tables are usually over-motored to secure very rapid acceleration and reversal, so that the motor will overspeed very quickly if it is series wound. If the motor while running at high speed is reversed with part or all of the resistance short-circuited, damage is very likely to result.

As to damping the magnetic circuit of series wound switches to prevent their too-early closure, this is not at all necessary in switches for use with shunt and compound wound motors. In fact, it is objectionable at least with the form of switch described in this paper, because closure of successive switches is unnecessarily retarded.

In the case of larger series wound motors, which give a circuit of high self-induction, causing the motor current to build up gradually, there is a tendency for the switches to close before the current has reached the lock-out value for which the switches are adjusted. However, the series wound switch is no more subject to this action than the ordinary "throttles" or accelerating relays which have been used in the past.

Even in the case of large series wound motors it has been found that if the resistance may be so proportioned that peaks of current equivalent to 150 per cent of the current at which the switch is adjusted to close, occur at the closure of each suc-

Digitized by Google

cessive resistance switch, reliable locking-out of the switches occurs without resort to any specific means for retarding the action of the switches.

As to the matter of holding in the switches, this paper illustrates in Fig. 5 the use of a shunt holding coil on the last resistance switch, and in Fig. 15 the use of series coils throughout.

Admittedly the series coil is simpler in its connections and is more sturdy in construction, but its use has decided limitations. It has been found that in a surprisingly large proportion of motors, particularly those driving machine tools, the armature current frequently approaches very close to zero, and in the case of tools or machines equipped with fly-wheels, upon a sudden drop in line voltage the motor acts as a generator returning current to the line. This causes the last switch to drop out and insert all of the starting resistance in the motor circuit, and, when the motor has slowed down slightly, the resistance is again automatically cut out. This introduces an objectionable pumping action in many instances. The shunt holding-coil is free of this objection, as it leaves the motor connected to the line and free to return current to the line at the instant of a sudden drop in voltage.

The use of the series holding coil also introduces a resistance in the armature circuit which is objectionable in shunt wound motors where constant speed is required.

Ragner Wikander: I want to ask Mr. Eastwood and Mr. Murphy whether they have made any tests of the application of this principle, possibly somewhat modified, to alternating current?

Arthur C. Eastwood: In answer to the question as to the adaptability of this form of switch to alternating current controllers, I will say that experiments have been made in that direction which are very promising. I am not, however, prepared to go into detail on the subject at this time.

Theodore Varney: I would like to ask Mr. Eastwood if he has found any satisfactory means of notching back with the controller he described, that is, opening the switches one at a time, without opening all of them.

Arthur C. Eastwood: As to the question of " notching back " the controller, that is reducing the speed of the motor step-by-step, the connections of the series wound contactors lose a great deal of their beautiful simplicity when this must be done.

There is no particular complication in a controller for " notching up " the speed of the motor step-by-step. Such a controller is shown in Fig. 19 of the paper.

When it is desirable to reduce as well as to increase the speed of the motor in a step-by-step manner under the control of the operator, a controller such as that shown in Fig. 20 may be used. In this controller the resistance switches are actuated by shunt wound magnets, and are governed as to the time of their closure by individual series relays.

Digitized by Google

DISCUSSION ON "ELECTRICALLY DRIVEN REVERSING ROLLING MILLS." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions)

Karl A. Pauly: I wish to call attention to Fig. 2, which shows the relative economy of the two types of mill. For examination of these curves it will be seen that the power consumed by reversing and non-reversing mills is practically the same from one-half load to 50 per cent overload, the difference being only five per cent and in favor of the reversing mill at loads of 90 per cent of full load and below, and in favor of the non-reversing mill at loads above 90 per cent of full load.

While the percentage difference in power consumed by the two types of mill is considerable at light loads, the actual difference in power consumed is comparatively small and should have little effect on the total power consumed by a well designed mill.

Further, the real measure of the efficiency of a mill is the cost per ton to roll the steel including in this cost the fixed charges on the total investment properly chargeable against the mill and the total operating costs, including the costs of labor, maintenance, repairs, supplies and power.

A reduction in the power consumed affects one item only of the total cost of rolling, while the improvement in the quality of the product or an increase in the output affects all the factors, and those questions are usually the determining factors in the choice of the type of mill.

The speed with which steel can be rolled depends, among other things, on the shape and size of the section, it being possible and often necessary to roll a small simple section at a higher speed than a large irregular section. From this it follows that where a large variety of sections are to be rolled in a single mill, as is frequently the case in small plants, it is often more economical to adopt the reversing mill with its wide range of speed than the three-high mill, the range of speed of which is limited.

However, in America the tendency in modern plants is to specialize the products of the mills, rolling a limited variety of sections, either directly from the ingot or from prepared billets in large continuous mills made up of several stands of rolls. In a mill of this type but a few passes and in many cases but one pass is rolled in a single stand. A mill of this type can obviously be driven either by a number of constant speed non-reversing motors, one per roll stand, or a single motor geared to the several stands. All but one of the mills at Gary and many of the modern steam driven mills are of this type.

There is a class of mills known as universal mills which, because of the difficulty of building a three-high mill of this type and the small difference in cost between the reversing and non-reversing steam engine, has been practically universally driven by reversing engines. The very high cost of the electrically driven reversing rolling mills led to the development of a non-reversing universal mill, an example of this type being the

Digitized by Google

60-in. universal plate mill at the Gary works of the Illinois Steel Company. This mill is driven by a 6500-h.p., two-speed, changeable-pole, induction motor.

Also with a view of improving the economy of existing reversing mills and avoiding the high first cost of the electrically driven reversing mills, it has been proposed to operate low pressure turbines in conjunction with these mills, a regenerator being installed between the engine and the turbine.

While a number of electrically driven reversing mills will doubtless be installed in America, the indications are that the number will be much more limited than has been the case in Europe.

The slip regulator described may be made extremely sensitive by the use of ball bearings; in fact, we have built such a regulator which, when operating at full load, held the demand for power within two per cent either side of the mean.

Dr. J. Puppe has made a large number of tests to determine the power required for rolling steel of various sections and carbon contents. These tests and others indicate that when steels containing a considerable variation of carbon contents are rolled at the same temperature, the power consumption for a given elongation varies only slightly with the variation in carbon content.

It is pointed out in the paper that the curves given in Fig. 7 apply only to a limited number of sections. We have made extensive tests with a view of determining the power required to roll sections which differ widely from those given, such as sheets and plates both hot and cold rolled, and find that the power required for a given elongation may be much greater than that shown. Further, the friction varies widely with different types of mills, the friction load of some mills such as cold mills being a large percentage of the total power consumed.

In contrast with the cold mills we have the puddle mills. The power required during the early passes for a given reduction is much less when rolling puddle bar than when making a similar reduction in solid steel.

F. G. Gasche: The object in preparation of this paper is stated on the first page to be: "To briefly review the more important points in the design and operation." As the development of the subject matter introduces many observations to which we might not all agree, a specific analysis of such observations may be advisable in order to uncover, if possible, the economic tendencies in rolling mill practice and design.

Two questions can be propounded at the outset, and will serve to illustrate the attitude of the iron and steel interests today on the roll drive problem if we may judge by the treatment accorded to these matters in the recent past.

1. Is the reversing rolling mill advisable or necessary?

2. Is the Ilgner system the best method of driving the reversing rolling mill?

Digitized by Google

The reversing mill has been attractive to mill operators for reasons that have been stated as applying to European practice, *viz.*, facility in accommodating rapid changes in class of product and particularly for small orders in each class. A prominent advantage of the reversing mill consisted in the ready application of vertical rolls, operating simultaneously with the main rolls and effective in squaring the edges of slabs, plates and bars, where such a contour is desirable. The production of sharp corners on rolled sections is difficult with grooved rolls characteristic of the three-high or continuous train construction of rolls. Another advantage, which with modern construction is less apparent, is the absence of lifting or tilting tables peculiar to the three-high mill construction. Withal, the reversing mill offered a cheap and flexible mill construction, easily adaptable to a wide range of product and particularly attractive to the small plant and erratic demands for product.

The transformation from reversing mills to three-high construction commenced before the application of large electric motors to roll trains was a possibility. Commencing with the smallest roll trains and with better constructions available there has been a gradual appropriation of a certain part of the rolling mill business by the three-high trains such that there is scarcely a class of product which is not rolled by the three-high or continuous train with advantage over the reversing train. The part of the rolling mill work that has been thus diverted to three-high mills consists of the assured heavy orders of a given class of product sufficient to meet the capacity of the mill. The simple reason for this evolution of mill types is the commercial advantage after a certain state of business is realized at a given mill. I take exception to the observations of paragraph 2 above Fig. 1 of the paper, as it is contrary to the experience with the two types of mills, irrespective of the method of driving the same, with the foregoing qualifications concerning the class of mill orders.

The author of the paper has apparently overlooked the fact that reversing mills necessarily involve the inclined "spindles" or connections from driving mechanism to the rolls, the angular position of which imposes very heavy end thrusts on roll necks and other rotating parts in the system. Under the conditions of service the work lost in friction is certain to be a larger percentage with the reversing mill than with a properly aligned three-high train. The assertion in the second paragraph concerning the loss of continuously operating train as compared with the motor generator set remains to be proved, as the continuous train motor can be stopped when the service of the mill is interrupted, but the nature of the alternating current motor-direct current generator operation precludes anything like such intermittent service.

A recently completed three-high mill at the Gary Works, which the members of the Institute will examine, operates on a

Digitized by Google

class of product and service which heretofore was considered the domain of the reversing mill. A continuously rotating induction motor with a suitably large flywheel is capable of ready control to two rotative speeds, which range is sufficient to meet the requirements of great variations in the size of slab and class of product. Vertical rolls have been retained, while tilting tables serve for manipulations of the slabs with an expenditure of energy that is insignificant in comparison with the irrecoverable energy losses due to impact of gears, spindles and other connections inseparable from the reversing mill construction. It may be added that the Ilgner system of drive was carefully considered for this particular mill and was abandoned for the following reasons:

1. The combined efficiencies of transmission and transformation of energy from shaft of prime mover to rolls was less than the three-high construction would offer.

2. The cost of the Ilgner system was prohibitive in comparison with the type that was adopted.

With the movement toward concentration of rolling mill work in large mills especially adapted to segregated classes of product and the accompanying continuous service, the economic tendencies answer the first question and indicate that in the ultimate development in this country the reversing mill is neither necessary nor desirable.

The second question as to the suitability of the Ilgner drive for reversing mills brings up the subject of overall efficiencies from prime mover to roll train, and cannot be disposed of by the comparisons referred to above Fig. 6. The Ilgner system involves from prime mover shaft to rolls three transmissions of energy and four transformations of energy, the continued product of the efficiencies for which must be compared with the efficiency of transmission of a direct connected prime mover. Without exhibiting the actual efficiencies applying to the operation of a certain Ilgner system, it can be stated that a mechanical advantage in the ratio of almost two to one exists in favor of the direct connected prime mover.

The construction referred to below Fig. 6 in the paper is today obsolete in view of the demonstrated possibilities of non-condensing compound steam engine combined with the most recent types of low pressure turbo-generator sets.

R. Tschentscher: Mr. Sykes mentions that the pioneer work in reversing rolling mill motor drive occurred abroad. I wish to relate the following in this connection as it is quite possible that some credit should remain in this country:

Approximately December, 1905, at the South Works of the Illinois Steel Company, I installed a reversing drive motor generator set consisting of 25-h.p., 250-volt, compound motor, coupled to a 75-h.p., 250-volt, compound motor, which drive was coupled to three 8-in. by approximately 50-in. diameter steel slabs as flywheels. The 75 h.p. motor on this set, acting as

Digitized by Google

generator, was connected to a 75-h.p. motor of same type geared to a small train of two-high rolls. Crop ends of rails were cut in two lengthwise and the heads were rolled into flats in this train of rolls. The operation of this small experimental drive convinced the Illinois Steel Company engineers of the practicability of such a drive on a larger scale. Specifications were accordingly arranged for the purchase of entire electrical equipment for a two-high reversing 30-in. universal plate mill, placed in operation June, 1907.

It is somewhat difficult to discuss reversing rolling mill drives without introducing the question of the relative merits of two-high and three-high mills. A few points in this connection are offered.

Reversing two-high mills have the following commercial advantages over three high mills.

1. Instant stopping of reversing mill in case of trouble—broken spindle, roll, collar, accident, etc.

2. Less maintenance cost of two-high reversing mill equipment. This is due to less operating parts, smaller weight of operating parts, less actual time of operation of parts and more "trouble anticipating jobs" performed, due to the convenient and ready means of shutting down mills for short periods.

3. In smaller plants, it is very desirable that a miscellaneous assortment of finished product should be obtained from a mill. This can be better accomplished in a two-high than a three-high mill. In a two-high mill, rails, shapes, plates and merchant steel may be obtained while in the three-high mill one is practically limited to a single kind of finished product. In plants comprising a considerable number of different mills, this factor is not so important in times of full operation of the plant. However, in times of partial operation, due to business conditions, the large plant assumes the characteristics of the small plant. For the past few years, this point has assumed considerable importance and we are not certain that this condition of affairs will not exist for a considerable period in the future.

4. As a general statement, the percentage of salable product is higher on a two-high mill than on a three-high mill, due in a large measure to the speed control of the two-high mill permitting a slower forging operation during the early passes and high speed rolling operation during the last passes.

5. The relative amount of finished product obtained from a two-high and a three-high mill is not easily determined. Practically all depends upon local considerations, the size and shape of the initial ingot and the size and shape of the finished product being the governing factors. In a mill rolling finished 8-in. by 8-in. billets from ingots of large size, it is probable that the three-high mill has more capacity. In a plate mill rolling from slabs to finished plates, it is probable that the two-high mill has the greater capacity.

6. Less roll friction load for two-high mills. The power re-

Digitized by Google

quired for driving motor generator set will vary from approximately 50 to 200 kw. compared with 300 to 800 kw. for three-high mills.

7. Starting load on three-high mill is very much in excess of that of motor generator set on two-high mill in spite of any commercial barring motor arrangement which may be installed. This means, of course, a severe tax on power stations and, to this extent, larger power stations are required for three-high mills. In small plants or in those purchasing power, this becomes quite a serious item. In larger plants, this point is not so serious.

8. The question of relative efficiency of reversing and continuous rotation, drive is not easy of disposition. If the full load operating conditions of the local electrical drive are considered, then the economy of the three-high is no doubt better than that possible with any two-high drive under the same conditions. However, the use of such figures in a commercial analysis on the basis of steel mill operating conditions such as they *are* (not as we would like to have them) will prove very misleading. An attempt must be made to arrive at the yearly economy. This is affected by a large number, at the present time, uncontrollable factors in the local mill. The intermittent operation of steel mills due to orders—or lack of orders—local mill operating conditions such as operation of reheating furnaces, conjested hot beds, mill breakdowns, etc., plant operating conditions such as irregular steel supply due to a large number of causes out of the control of the local mill, are of much more importance in influencing the question of yearly economy than the relative figure of full load economy of the electrical equipment. Furthermore, the power station demands will be greater and the peak loads higher with a three-high mill than with a two-high mill and the yearly economy of the power generating equipment, under such conditions, is an important factor.

9. The higher first cost of two-high reversing mill electrical equipment is compensated for to a considerable extent in the three-high mill, by materially higher first cost of mill proper and by higher investment due to the larger power generating equipment being required. No broad general statement can be made to cover the point of the relative first cost of reversing mill equipment and three-high mill equipment. Each condition must be analyzed but in such an analysis, one must not cease calculations after covering the electrical equipment *within* the roll motor room. As mentioned, the cost of the mill equipment and the cost of the transmission and generating system must be seriously taken into consideration.

Theodore Hoock: Mr. Sykes presented a complete and up to date table of all reversing rolling mill installations.

The power consumption of this kind of service is the most severe and variable one on the machines. The maximum output runs up to 15,000 h.p. and the momentary overload reaches 5 to 6 times the normal rating. In addition the motors are to

Digitized by Google

be reversed continuously which requires brush setting at the neutral from full speed in one direction to full speed in the other direction within three to five seconds.

Referring to the installations No. 1, 2 and 4 in the table, which were built in 1905 to 1907, following points were leading in choosing the type of generator and motor.

The sparkless commutation was only obtainable by auxiliary poles. The sudden peak loads made the distributed compensating winding desirable for several reasons. The quick variations of the armature field cause a corresponding increase of the voltage between segments underneath the pole tips which leads to flashing in case no compensating windings is provided in the pole face. That is especially the case when the main field is weakened. The segment voltage remains almost constant with the compensating winding at any load and a smaller number of commutator bars is feasible. The maximum voltage between segments can also be kept low with the auxiliary pole type, but it requires a considerably larger number of bars, that is a larger and longer commutator. Since the compensating winding prevents field distortion it is feasible to build this type with a smaller air gap, which has the advantage of decreasing the air gap ampere turns and the time constant of the main field winding of the generator. The quick field reversing, the small remanence in the yoke iron and the lower reactance of the field coils decided for the laminated yoke and the compensating winding. The laminated yoke has also the advantage that the commutating field path has practically the same permeance as the armature and the commutating field is built up as quickly as the armature current has to be commutated to prevent sparking and flashing.

The inertia of the motor is to be small which leads to a small diameter and long core. A low speed auxiliary pole machine with bodily poles and solid yoke and 20 in. core length is difficult to keep cool. The large rolling mill motors No. 2 and No. 4 could have double this length because the yoke iron was laminated in line with induction motor practice.

Wilfred Sykes: With reference to the remarks of Mr. F. G. Gasche regarding the possibility of rolling all classes of materials on three-high mills, I believe this is not doubted by any one familiar with rolling mill practice—the question as to whether it is advisable, however, is open to discussion. As pointed out by Mr. Tschentscher, the reversing mill is of particular value in a small plant, but this type of mill can also be used to very great advantage in the larger plants for rolling small quantities of largely varying material, which would be difficult with a three-high mill. Mr. Tschentscher's statement that a large plant in bad times approximates very closely the operating characteristics of a small plant, seems to me to state the case very well.

Mr. Gasche takes exception to the statement that the reversing mill is more economical than the three-high mill when

Digitized by Google

working on partial output, as being contrary to experience with this class of mill. I presume that he refers to steam driven mills, as this is certainly not the case with electrically driven mills, as has been repeatedly demonstrated in Europe.

The statement that the continuously running motor may be stopped during intervals applies equally well to motor generator sets, as it is common practice to cut off the current from the driving motor of the motor generator set and let it coast when the interval is likely to exceed 10 or 15 minutes.

The reference to the three-high 60-inch plate mill at Gary raises the question which cannot be disposed of without some discussion. This mill is driven by a two-speed motor of 53½ and 107 rev. per min., the roughing passes bieng made at the slow speed and the finishing passes at the high speed. This necessitates accelerating the motor from 53 to 107 rev. per min. during the rolling of each plate and retarding the motor when the plate is finished in order to have the correct speed for the next slab.

On account of the low speed of the motor during the first passes, it is necessary to have considerable flywheel effect in order to obtain a reasonable equalization of the load. At the high speed when the stored energy is four times as great, the flywheel effect is not so important as the power requirements are usually less for the finishing than for the roughing passes due to the fact that the amount of work that it is possible to do on the plate per pass is limited by what the material will stand without injury, consequently the maximum loads are not so great as when roughing.

In order to facilitate the changing of the motor speed the flywheel effect shoud be as little as possible, otherwise considerable time and energy will be lost. It will be seen that the two operating conditions, with such an arrangement, are antagonistic.

In the case of a reversing mill, the inertia of the motor is kept as small as possible, and therefore it is easy to obtain the higher speeds for finishing. The flywheel of the motor generator set takes care of the fluctuations in power and consequently it is possible with the reversing motor to obtain a large range of speeds and operating conditions, at the same time to effectually equalize the load on the power plant.

With the arrangement at Gary two speeds only are obtainable, whereas with the reversing mill a gradual increase is possible and thereby a great average speed is obtained which enables the output to be increased. This is of particular value when rolling long plates and reduces the power consumption as with quicker rolling the final temperature is higher.

Regarding the statement that the inclined spindles of the two-high mill cause the considerable losses, this is contrary to tests made by the writer which indicate that there is very little difference in the friction load of a properly designed mill, no matter what the position of the rolls may be.

Digitized by Google

Mr. Gasche's statement that the Ilgner system is less economical than the direct connected motor, on account of the various transformations, would appear on the face of it to be correct, but as pointed out in the paper, this is not the only feature to be considered and the curves shown are the results of tests made on various mills and indicate that as far as the power required from the line for a certain rolling work is concerned, there is at full load very little difference between the three-high and the reversing mill.

When the question of the input to prime movers is considered, the only basis of comparison should be the number of heat units required for the various systems. In order to clear up this point, I have prepared a number of curves, see Fig. 1, which show the results obtainable with various arrangements. In order to com-

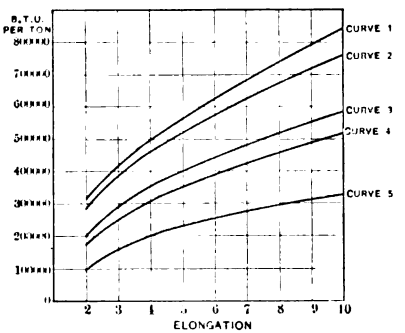


FIG. 1

Heat units require per ton for rolling blooms or billets in reversing mill at full capacity
Curve No. 1.—Steam drive saturated steam condensing 130 lb. 26 in. vacuum.
Curve No. 2.—Steam drive superheated steam 80 deg. fahr. 130 lb. 26-in. vacuum.
Curve No. 3.—Electric drive turbine driven generators steam 150 lb. 100 deg. fahr. superheat 28 in. vacuum.
Curve No. 4.—Steam drive combined with exhaust steam turbine 130 lb. 80 deg. fahr. superheat 28 in. vacuum.
Curve No. 5.—Electric drive gas engine driven generators.

pare the different methods of driving, I have reduced all results to the number of heat units required in the fuel to roll the steel. These figures are on the basis of rolling ingots to blooms or billets or similar work when only direct pressure comes in question and the temperature range is from about 2200 deg. fahr. to 1800 deg. fahr. The values shown are the heat units required in the coal or gas and all the various losses that occur have been considered. Curve No. 4 shows the results obtained from a test on a double tandem reversing engine of the latest construction built in 1909, the exhaust steam being used by a suitable turbine coupled to generator. The steam consumption figures are the result of a test extending over 16 hr. during which 645 tons of ingots were rolled to billets of various sizes. In separating the output of the turbine and engine, I have divided the total heat units in pro-

Digitized by Google

portion to the actual work performed by each. During these tests, the average steam pressure was 130 lb., the super heat 80 deg. fahr. and the vacuum about 28 in. so that the conditions were such as to give results as favorable as could be expected with such an arrangement. The loss in the piping has been taken at 5 per cent which corresponds to the average condition and the boiler efficiency has been taken at 70 per cent which was the figure obtained during a four weeks test at the same plant, the boilers being of the watertube type with chain grates. Curve No. 2 shows the steam consumption of the engine working without the turbine and exhausting direct into the condenser. These figures check very closely with those of Ortmann (*Stahl and Eisen*, 1908, page 577)—made on similar plants and are based on the same steam conditions as when running with the turbine. To show the effect of the superheat, curve No. 1 has been drawn which shows the consumption when running condensing with saturated steam.

In order to compare an electrically driven mill with turbine driven generators, curve No. 3 has been worked out from results obtained with electric drive and on the basis of a steam consumption of 17½ lb. per kw-hr., at 70 per cent load factor, 150 lb. steam, 28 in. vacuum, 100 deg. superheat.

The lowest heat consumption is that with gas driven generators and electric drive. Tests in this country and abroad show that an average thermal efficiency of 20 per cent is obtainable with gas engines with a load factor of about 70 per cent and taking the results of tests on electrically driven mills, the combined figures have been obtained, which check up closely with European results. A load factor of 70 per cent on the machines has been assumed as it is quite possible to obtain this value under normal operating conditions and in a well run station it would be exceeded, but this should not be confused with the load factor of the station.

From these curves it will be seen that the gas driven generator and electrically driven mill is by far the most economical arrangement and as most modern steel plants are using the blast furnace gases directly in gas engines for the production of power, it is plain that the electrically driven mill presents great advantages from the standpoint of economy. The use of electricity allows of the disposition of the plant in any way convenient, whereas with steam driven mills, they must be located in relation to the boiler house and this necessarily imposes restrictions which cause the plant to become congested. The figures given for the steam driven plant with exhaust turbine are the best that can be obtained and do not take into consideration the effect of interruption in operation of the mill when live steam must be used to keep the turbine running. In the case of a reversing mill, the actual time the engine is running is comparatively short and when work is irregular, it is often necessary to use live steam. Experience in Europe tends to show that the

Digitized by Google

net economy of the combined engine and turbine over a year's run, is practically the same as the electrically driven mill furnished with power by high-pressure turbine driven generators, although in the opinion of some operators, it is a good deal lower. The disadvantage from an operating standpoint of such an arrangement which involves so many restrictions, does not in my opinion justify its adoption for new plants. As will be seen from the curves the saving that can be made with this arrangement under the most favorable conditions assuming that live steam is never necessary, is in any case not very great.

Mr. Gasche's statement that the use of a throttle valve between the receiver and the low pressure cylinder is obsolete, does not line up very well with modern practice. For a statement as to the modern practice for reversing rolling mill engines, see *Stahl and Eisen*, January 19, 1911, page 97.

That the first cost of the reversing mill electrical equipment is greater than that of a three-high mill, is obvious, but when the total cost of the installation including the mill itself and all auxiliary equipment is considered, the extra cost is surprisingly small and this is of course the only basis on which any comparison can be made. The effect that the type of drive has on the generating station is of the utmost importance and as pointed out by Mr. Tschentscher, it is not only the equipment in the motor room that must be considered.

Regarding Mr. Tschentscher's remarks, it is very interesting to note the experiments made at the South Works of the Illinois Steel Co. in 1905 and there is no doubt that a great deal of credit is due to the engineers of the company for the installation of the reversing plate mill at these works. As mentioned in the paper, this mill was designed and was being constructed before the first European installation was started. With reference to the curves given in the paper showing power requirements, it should be noted that these represent average figures. Tests show very widely varying results due to a number of causes, but the figures given may be taken as representative of the results obtained when rolling simple sections of moderate size. When rolling smaller sections, the power will be greater as the metal is liable to become colder. The power required may aslo vary with the quality of steel, this however, is not due to the chemical composition, but rather to the fact that high carbon steel must be rolled at a lower temperature than low carbon steels. Tests indicate that at temperatures above 900 deg. cent. the chemical composition of the steel has practically no influence upon this strength.

Digitized by Google

DISCUSSION ON "THE APPLICATION OF CURRENT TRANSFORMERS TO THREE-PHASE CIRCUIT," "COST OF TRANSFORMER LOSSES." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(*Subject to final revision for the Transactions.*)

A. H. Pikler: It is now more than 26 years since the first large transformer installation was made in Budapest, Hungary. Both the system of operation of distributing-transformers and the transformers themselves were inventions of Messrs. Zipernowsky, Déry and Bláthy. The parallel system, or as it later was called in this country, the multiple arc system is used today exactly as it was in use then, and the general design and construction of the transformers of that time has undergone very little change in comparison with the transformers of the present day. Most of the changes or improvements which we find in the present transformers as compared with the first types are due to the improvement in the materials, as insulating materials and the steel used; further to the increase in cost of labor.

That the distributing-transformers are still of acute importance is shown by the present paper. The reason for this is the very large amount of capital invested yearly in such transformers, and the large amount of money expended in operating them. The Bureau of Standards of the United States Government, recognizing the great importance of the subject of distributing-transformers, went into a thorough investigation of the value of the various characteristics of such transformers expressed in dollars and cents, and a few years ago issued the Circular No. 22 where a report of the investigations is found in connection with other useful suggestions relating to the same subject.

The paper written by Messrs. Stone and Atkinson is to my knowledge the first one that takes into consideration *every* single item affecting the operating cost of the transformers, and gives a thorough and full presentation of the whole subject. The manner in which the authors deal with this subject I consider classical because not the least little detail is lost sight of from the power house to the consumer. The important difference between the government circular and this paper lies in the fact that Messrs. Stone and Atkinson point out the method whereby by operating cost corresponding to the exciting current and regulation may be taken into account in the same way as the core loss and copper loss.

By this additional information the transformer purchasing public is put into a better position as to the selection of the most economical distributing-transformer. By the use of a high magnetic density in a transformer core, the dimensions of the magnetic circuit will be decreased and a small transformer will be obtained of considerably lower cost than when using a lower magnetic density. If considering the core and copper loss only in comparing the high magnetic density transformer with one having a low magnetic density, on the basis of evaluation

Digitized by Google

used in the government circular, it may frequently be found that the lower losses in the transformer of generous amount of material may not suffice to quite offset the difference in price between the two transformers. If however the exciting current is also and rightly taken into consideration, such will not be the case.

Another important point which the authors bring up and which may bear some further illustration is that the low power factor in a transformer in itself is not objectionable when it is accompanied by a low core loss.

I have often heard statements like this:

" The introduction of silicon steel does not mark such a great gain in the transformer as it may appear from the core loss watt-per-pound figures of the ordinary and silicon steels. The power factor at open circuit in the silicon steel transformer has decreased considerably as compared with what was in the transformer built with ordinary steel. Therefore what we gain in core loss in the transformer we lose on the line due to lower power factor."

That the logic of this statement is not correct may be seen from the following:

Let us assume for instance two 5-kw. transformers. One of the old type made with ordinary steel, another of a recent type made of silicon steel. The old type transformer has a core loss of 64 watts, the modern transformer has a core loss of 45 watts, the exciting current of both transformers is the same, that is, say 2 per cent of the full load current. Then the old type transformer will have a no load power factor of $\frac{64}{0.02\times 5000}$ $=64$ per cent. The modern transformer will have a power factor of $\frac{45}{0.02\times 5000}=45$ per cent. The power factor of the old transformer is higher than the new one. But is the old transformer therefore a better transformer? It is not, because the exciting current, *i.e.*, the no load current on the line is just the same, moreover in the new transformer we have a transformer which in connection with that same exciting current has a lower core loss.

Another item of importance that may be pointed out in connection with a magnetizing current which is of value to the purchaser of transformers is as follows: If the normal magnetic density in the transformer core is higher in one transformer than in the other, then a slight increase in line voltage may cause a very large increase in the exciting current of the transformer having the higher magnetic density in its core. This is self explanatory from the well known saturation-curve.

I do not agree with this statement of the authors: " Transformers are designed and will be designed and sold to meet the

Digitized by Google

demands, regardless of the cause of the demand." I consider it rather academic and do not believe that it coincides with the real, actual development of the transformer. Not only a transformer but any kind of machinery is made by the manufacturer so as to produce it with the greatest economy to both the manufacturer and the public. The public buys what is offered to it. Later on competition steps in and causes further improvements in the apparatus. It is therefore the competition that creates further development in the art and not the demand of the public. The public generally specifies the best performance offered by the various competitors.

That the decrease in core loss and copper loss require a greater expenditure of material can be appreciated from the figures given by the authors stating that 1 per cent decrease of both losses requires about 3.3 per cent increase in the cost of the active material.

There is a paragraph in the paper where it is explained why the loss of the amount of material per kilowatt is less with increasing capacities. I beg to offer the following explanation, which I think is broader and clearer: Let us consider a transformer or any other electromagnetic apparatus with linear dimensions of unity; if these dimensions are doubled, then the volume of material and with it the weight will be increased as the third power, the cross section of the iron core and with it the total magnetic flux will increase with the second power. The cross section of the copper and with it its current carrying capacity will also increase with the second power. Since further the output of any electromagnetic apparatus can be expressed as the product of magnetic flux and ampere turns, it may be seen at once that by doubling the linear dimensions of the apparatus, its output increases with the fourth power whereas the amount of material increases with the third power. Using the same densities in both cases, the watts lost are directly proportional to the weight of the material. Therefore it will be readily seen that the apparatus of the larger output will have a lower loss per kilowatt output, that is, a higher efficiency. It should have been pointed out however by the authors that the radiating surface increases only with the second power and this influences the design in a much greater measure than does a change in the winding space factor, as is the authors' opinion.

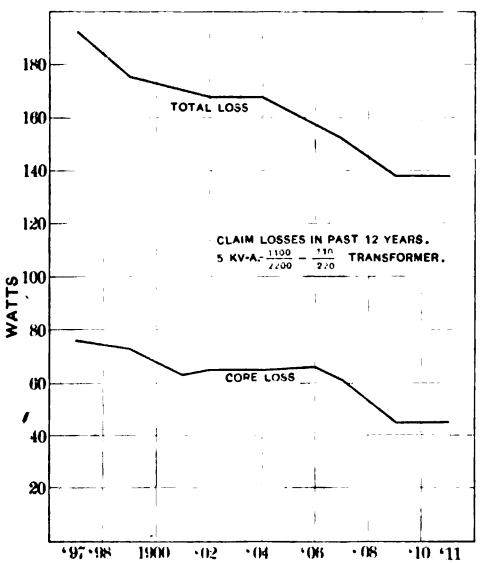
In closing I wish to point out the fact that the significance of the various items entering into the real economy of the transformer can be best appreciated by the figures given at the close of the paper, which show that whereas the initial cost of a 5-kw. transformer for instance is approximately $60, its operating cost will be of the order of $50; so that the total cost of the transformer to the purchaser will amount to $122 to $147. This is the total cost assuming a 10 year life and capitalization with interest at 6 per cent, taking into account depreciation and interest.

Digitized by Google

W. C. Smith: Viewing the question of transformer losses from the manufacturers' standpoint, I would like to add a few words to the discussion of the excellent paper by Messrs. Stone and Atkinson.

That the cost of losses is an important consideration in the selection of distributing transformers, even approaching a value equal to that of the transformer itself, has been clearly shown by the authors.

The demand of the central station for lower losses has been insistent, until today, for a given kv-a. rating the distributing transformer is the most efficient piece of electrical apparatus on the market. The improvement in core loss by the introduction of silicon steel has, of course, been one of the greatest contributing factors in this development. The actual watts per lb. at normal



Curve of Losses

working densities, due to hysteresis and eddy current losses, has, within the lifetime of the average transformer, been reduced at least one-half.

A curve of losses on the 5 kv-a. standard lighting transformer, as given in published claims of a prominent electrical manufacturing company in this country, shows the remarkable decrease that has been accomplished during the past few years.

With such marked reductions in the losses, combined with better mechanical construction in the new types as they were put on the market, a very high depreciation value naturally had to be placed on apparatus already installed. In other words, the " smashing point " was reached early in the life of the old lighting transformer.

Digitized by Google

Today, conditions are changed. In the best class of this apparatus now on the market, every part has been scientifically proportioned. There is no waste space anywhere. The construction is extremely rugged and the heating uniform. With steel absolutely non-aging, the customer is assured of proper division of losses and constant efficiency. The processes of manufacture are such as to warrant long continued service without disturbance of the various parts.

In other words, the best class of modern distributing transformers is now built primarily for long service. No radical mechanical changes can be anticipated, which will warrant replacing these units. Only a very material reduction in losses can suffice for such replacement.

However, with efficiencies already of 97 to 98.5 per cent, any very material saving in power cannot be anticipated even though the present losses be decreased by a fairly large percentage. No improvement is of course expected in the quality of copper. It is too much to hope for any marked improvement in the permeability of the steel, which means that, even though the core losses per lb. be considerably reduced, it will not be possible to operate at higher flux densities due to magnetizing current considerations. We must, for these reasons, look toward the core losses for any great improvement in efficiency. But even assuming a 25 per cent decrease in core loss (and this is hardly probable) we shall only find 8 per cent decrease in total losses, due to the fact that the present division of losses is two of copper to one of iron.

With the foregoing facts in mind, the value of a small depreciation factor becomes at once apparent. Taking the typical case of a 5 kv-a. transformer already cited, if the life be increased from 10 to 20 years, interest at 6 per cent, the interest and depreciation factor will be $8\frac{3}{4}$ per cent. Assuming the same original costs, the increased life of 10 years can be shown to be equivalent to a 69 per cent difference in cost of total losses between two transformers giving the same length of service.

This consideration shows such a large saving, due to long life, as to almost eclipse the demand for lower losses which has been pressed so strongly upon the manufacturer during the past few years. Other factors remaining the same, lower losses will still be sought for. But a far greater consideration will be that of long life under continued service.

Rather than any marked decrease in total losses, resulting from improvement in materials, reproportioning of parts, etc., it is possible that the future may see a development toward higher operating temperatures, resulting in a cheaper transformer. Before the advent of silicon steel, aging required an 80 deg. cent. temperature limit. At the present time, the flow point of the impregnating compounds gives, let us say, an ultimate temperature limit of 90 degrees. It is possible that the development of synthetic gums will soon reach a stage to permit

Digitized by Google

of actual operating temperatures of at least 125 deg. to 150 deg. centigrade. Such a development will naturally present a problem to the oil refiner—a situation, however, which can undoubtedly be met.

E. A. Wagner: The paper by Messrs. Stone and Atkinson gives a basis of calculation for the comparative operating costs of different types of transformers which is of considerable value. The exciting currents, or magnetizing currents, are, as a rule, not given consideration when summing up the comparative values of transformers. A study of the formula will show, however, that the results obtained depend solely on the assumption made at the beginning, so that with different assumptions entirely different values will result.

In the summary of the losses Mr. Atkinson tabulates the value of two transformers of different characteristics, one a socalled high efficiency type, and another one a socalled low efficiency type. In the high efficiency type, according to this formula, the magnetizing current has a value of 62 cents, and in the low efficiency type a value of $3.78, thereby increasing the costs of exciting current more than five times with a transformer showing 50 per cent higher core loss. Such examples, given as typical illustrations, are apt to prove misleading to one not thoroughly acquainted with transformer performances. It is a matter of fact that magnetizing currents do not increase proportionately with the core losses. In transformer design we find that low costs and high efficiencies are arrived at by crowding the magnetic circuit (operating at densities close to the saturation point) and increasing the space factor by eliminating as much of the insulation between layers and coils as possible. Such a transformer, in comparison with one designed to operate at lower densities in the iron, but with a considerable heavier cross section in the magnetic circuit, assuming that modern silicon steel is used in the construction of the core in both cases, will show fully as high, if not higher, exciting currents. With a given quality of silicon steel, and retaining a winding space factor not varying more than 3 per cent, transformers of widely different characteristics in regard to core and copper loss and widely varying weights of copper and iron, will all produce very close to the same full load efficiency. In the design of this type, and assuming the valuations given by Mr. Atkinson, it will show that the socalled cheap transformers, or low efficiency transformers, will be much more desirable than the one which he classified as a high efficiency transformer. In other words, the choice of transformers is dependent almost entirely on the value of the magnetizing current.

H. B. Gear: I wish to emphasize the remarks made by a previous speaker regarding the importance of securing long life in modern transformer design. In the larger systems where the cost of energy has been reduced by large turbo-generators, until it approaches the vanishing point, the item of depreciation as-

Digitized by Google

sumes greater importance than the cost of the iron and copper losses. The larger companies are therefore becoming more interested in these days in the life of their transformers then formerly.

Although the iron losses in the line transformers in the Chicago system amount to approximately 6,000,000 kw-hr. per year, the cost of producing this energy is only about half the fixed charges—interest and depreciation—on the investment, based on an average life of 15 years.

Improvements in the methods of manufacture and insulation which would add five years to the average life of line transformers, are therefore fully as important as a reduction of 25 per cent in the core losses.

The operating engineer who endeavors to specify to the manufacturer a type of transformer which would be most economical in operation, must choose between a unit which will be most economical with lighting customers having a low load factor and a unit which is most economical for power customers having a high load factor.

The ratio between iron and copper losses should be lower for the consumers with small load factors and higher for the consumers with higher load factors.

It is not practical for operating companies to attempt to carry two kinds of transformers in stock for general distribution work and the operating engineer must therefore strike a happy medium which will be most economical for the average load factor of his customers.

R. W. Atkinson: I have been much interested in the points brought out by the various speakers. I shall refer to an objection made by Mr. Pikler to our statement that the manufacturer will adjust the losses to correspond with the demand. I think, however, that Mr. Pikler's idea is not really different from our original statement, namely: It does not make much difference whether the demand for any performance is for logical or illogical reasons or is because the salesmen of the various companies making transformers have convinced their customers that a certain loss should be reduced or that certain other losses should be left as they are. Two transformers of different performances will have a relative difference in their market value due to a difference in their performance. For instance, suppose that one has 90 watts iron loss and the other 100 watts iron loss. That difference of 10 watts iron loss will make a different sale value of the two transformers. Difference in value may be purely commercial, due to the fact that the salesmen have convinced the average user of the transformer that that difference is worth a certain amount to him, or it may be because the consumer has worked out, from either a logical or illogical standpoint that that difference means so much to him in dollars and cents. It does not make any difference what the basis of the demand is, the manufacturer will design his transformers to meet the demand of the market.

Digitized by Google

There has been a constant tendency to increase the temperature rise. As small transformers were built a few years ago, the limits were the efficiency. It was impracticable to build transformers with a high temperature rise, simply because they would have been so inefficient that it would not have paid to use them. At present, due to improvement in materials and design, the dimensions have been decreased more than the losses, thus increasing the densities, with a consequent tendency toward an increased temperature rise. If the insulating people can do what Mr. Smith hopes they may do there is a field now, as there formerly was not, for a material capable of withstanding high temperature.

A word in regard to the question of cost of magnetizing currents in the two transformers used in the problem. These were two particular transformers that were on the market at the time the figures were made. There is a tendency, I believe, for the high iron loss transformer to have high magnetizing current, although this is not necessarily so. I think the reason for this tendency was brought out by Mr. Wagner, that transformers are operated at densities very near the saturation point, and if the iron loss is increased with a given type of transformer there is a tendency for the magnetizing current to be increased in much greater proportion. Of course that can be *modified* by changing the design. The question of magnetizing current is a separate one from the others, and it is true that if the two transformers in the problem had about the same magnetizing current, and with the other figures as we have given them, the ultimate costs would not have been greatly different. The cost of magnetizing current is the most variable factor in the cost of transformer losses and depends largely on local conditions. If the transformer is put on the line with the purely lighting load, where the power factor is high, the magnetizing current will not be as expensive as if it were on a circuit of low power factor.

In regard to the relative ultimate cost of the low efficiency or high efficiency transformer, I would say that it depends very largely upon the purposes for which the transformer is to be used and the conditions of the cost of power. If the transformer is to be used for a long-hour load then it will pay to have a relative low copper loss and a relatively higher iron loss. I do not want to say, as a general statement, that it will pay to use either a low efficiency, or a high efficiency transformer, that it will pay to use a low ratio of copper loss as compared to iron loss, or to use a high ratio. The point we have tried to make is that each case must be figured out for itself.

Digitized by Google

DISCUSSION ON "ELECTROLYTIC CORROSION IN REINFORCED CONCRETE." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR MAY, 1911.)

(Subject to final revision for the Transactions.)

Burton McCollum: The paper by Professors Magnusson and Smith is an interesting and important one since it deals with a subject that has recently sprung into considerable prominence. A number of investigators have published papers on this subject during the last four or five years and much information has been brought to light. This paper carries our knowledge a step farther in several directions but much still remains to be done and it is encouraging to note that the authors are continuing this work.

The conclusions reached by recent investigators and which appear to be concurred in by the authors of this paper is that the failure of the concrete is due not directly to the passage of the current through the concrete, but indirectly to the corrosion of the imbedded metal and has therefore been described as an anode effect since the cathode does not corrode. It cannot be doubted that the most conspicuous effect occurs at the anode and the cracking of the concrete is no doubt due entirely to this cause. The Bureau of Standards has been carrying out investigations on this subject during the past year and among other things these investigations have brought out the fact that there is a cathode effect quite independent of the effect at the anode. The specimens in which this effect has been observed were of a size and form very similar to that adopted by Professors Magnusson and Smith, being cylinders with metal rods imbedded at the center. When these specimens have been placed in circuit with 15 volts pressure with the imbedded metal as cathode a distinct softening of the concrete near the cathode has been observed. The softening is confined to the region near the cathode, extending in some cases to about half an inch therefrom. No cracks however developed at the cathode. The cause of this softening has not yet been definitely determined but the matter is now the subject of investigation.

The effect of various voltages on reinforced concrete has also been studied and it appears that the time required for cracking of the concrete around the anode decreases much more rapidly than the current increases. The variation between individual specimens under the same treatment is so great that no definite law has been determined, but it is safe in general to say that the number of ampere hours required to crack a given specimen is much greater in case a low voltage is used than when a high voltage is applied, and this is true even when the voltages do not reach a value sufficient to produce serious heating.

A number of different brands of Portland cement have been tested. The specimens used in this test were 1:2½ :4 of Portland cement, coarse sand, and crushed trap. Specimens were made of each of the following brands of cement: Atlas, Dragon, Alpha, Lehigh, Pennsylvania, Giant. All contained imbedded elec-

Digitized by Google

trodes of 1 in. pipe cleaned and weighed, except the specimens of Giant Cement, which contained $\frac{3}{4}$ in. solid iron rods. Six specimens of each brand were used, but while the results differ considerably in some cases this difference is but little greater than is to be found in different specimens of the same kind of cement made at different times so that it is not to be expected that any one cement will prove materially more resistant to the effects of electrolysis than the others.

Several series of experiments were carried out using brass, carbon, copper and other electrodes. In the first series a pair of each were put in parallel on 15 volts direct current, one of the pairs being anode and the other cathode, (the other electrodes were sheet iron surrounding the cylinders in tap water).

All specimens are still uncracked after seven months run. After a month or two the cathode carbon specimen began to discharge a thick tarry substance at the top end of the carbon, apparently forced up through the core by pressure from below.

On the top of all the cathode specimens, the mortar had apparently disintegrated for about 1 inch around the cathode. To see whether this extended downward into the concrete, the carbon specimens were broken open. It was found that there was a softening around the core for about $\frac{1}{16}$ in. only, the softening at the top being confined to the surface layers.

The surface of the anode carbon had disintegrated for about $\frac{1}{32}$ in. No other effect was apparent. There was no certain evidence of loss of strength in either anode or cathode specimens.

An interesting comparison may be made by computing the number of ampere hours passed per sq. in. of anode surface. Cracking has occurred in the iron anode specimens when this quantity has amounted to a value ranging from 0.8 to 3.0. That for the carbon is 3.0 with no cracking.

In the second series, two pairs of specimens, having brass and copper electrodes, were arranged so that 1 copper and 1 brass specimen were put in series across 115 volt, direct current, both being anode; and 1 copper and 1 brass in series as cathodes on 115 volts.

No cracking of any specimen occurred during seven months run. At the end of this time all four were broken open, and the following points were noted:

The anode specimens were sound and hard, with no evidences of deterioration. Both anodes were considerably pitted, the losses being about 10 grams apiece, rather more for the brass than the copper. Greenish products of copper had penetrated $\frac{1}{4}$ in. to $\frac{1}{2}$ in. into the concrete from the electrodes. Ampere hr. per sq. in., 10.1.

The cathode specimens showed evidence of deterioration as described in the first series. The surfaces of the cathodes had the appearance of weathered copper, and a distinctly dark layer of disintegrated mortar extended for about $\frac{1}{4}$ in. to $\frac{1}{2}$ in. all around the metal. Ampere hr. per sq. in., 36.8. A peculiar feature is

Digitized by Google

noticeable in that the final resistance of the copper anode specimen is about 1/10 that of the brass anode specimen, while the reverse is the case in the cathode specimens.

Much work has been done with a view to throwing light on possible methods of protecting concrete from electrolysis. Since the most destructive effect is the cracking of the concrete due to corrosion of the anode it follows that if the anode can be protected from corrosion this trouble will be eliminated. The authors suggest doing this by preventing the current flow. Their observations on the effect of insulating materials on the bond between iron and concrete are confirmed by our experiments, although even greater reductions in the shearing stress have been noted. In one case, in which the rod had a rather heavy coating of pitch, it was forced out of the concrete by pressure which gradually developed from within. This would seem to indicate that the method of insulation should be resorted to with great caution if at all.

The suggestion made by the authors that iron might be coated with aluminum to protect it from corrosion is novel and worthy of serious consideration. It appears to have been established that if iron can be successfully coated with aluminum commercially this method could be used to protect the concrete from cracking. Perhaps the most obvious method of attacking this problem however, would be to take advantage of the insulating properties of dry concrete. Concrete, when dry, is a fairly good insulator, good enough in fact to prevent any appreciable corrosion under any conditions that might arise. We have therefore done a great deal of work on the subject of water-proofing concrete. A large number of waterproofing agents now on the market have been tried but with indifferent success. These tests have included those waterproofing agents that are to be mixed with the cement and also those that are to be applied to the surface of the concrete, as a paint. Not one of these agents, however, has shown sufficient tendency to reduce the damage or prolong the life of the cement, to justify its use in practice. Experiments now under way using treated papers, felts, etc., give promise of much better success. The success of these coatings, however, depends mainly on the insulating properties of the coatings themselves, so that it is immaterial whether the concrete is wet or dry. This is obviously important since it is difficult to secure dry concrete under practical conditions.

Another method of reducing damage due to electric currents is to employ some means of reducing the efficiency of corrosion; and a great deal of work has been done along this line at the Bureau of Standards. It has been found that in ordinary concrete the efficiency of corrosion is quite low, the actual amount of corrosion caused by the passage of a given number of ampere hours being of the order of from eight to 15 per cent of the theoretical maximum. This is due mainly to the presence

Digitized by Google

of a large amount of calcium hydroxide in all Portland cements. Attempts have been made to reduce the efficiency of corrosion still further by increasing the amount of calcium hydroxid and it has been found that this does reduce the corrosion to a considerable extent and its addition does not injure the cement, but on the contrary increases its strength somewhat and renders it somewhat less porous. The difference, however, even when 20 per cent by weight of calcium hydroxid was added to the cement, was not great enough to warrant the use of this method in practice since at best it could but delay the trouble for a little while. Other and more soluble hydroxides will doubtless give better results but it is not clear as yet what effect these may have on the properties of the concrete. Barium hydroxide has been shown to reduce the efficiency of corrosion very greatly. This is probably due to its reduction of the calcium sulphate present. All Portland cements contain a certain amount of calcium sulphate, the amount being in most cases of the order of 3 per cent by weight of the cement. This is added just before grinding the clinker and serves the purpose of retarding the setting of the cement. Experiments carried out at the Bureau of Standards have shown that the greater part of the electrolysis is due to the presence of this added calcium sulphate. When barium hydroxid is added to the cement the sulphate is precipitated out as the insoluble barium sulphate and in this way the efficiency of corrosion has been reduced to a fraction of one per cent. Other experiments have been made using specially ground clinker to which no calcium sulphate has been added. This however was not entirely free from sulphate, there being a residual about 3/10 per cent present in the ordinary course of manufacture, or about 1/10 the amount present in ordinary commercial cements. Specimens made up with this cement showed a corrosion efficiency of but a small fraction of 1 per cent. The great difficulty in using this lies in the difficulty in making sound concrete when the calcium sulphate is absent, owing to the very rapid setting of the cement. This is very troublesome even in the laboratory and in practice it would no doubt be prohibitive unless some means other than the use of calcium sulphate can be used to retard the setting of the cement. In making laboratory specimens this trouble may be largely overcome by using ice water in mixing the cement, and it is possible that this might also be accomplished in practice. Much additional work remains to be done, however, before the practical value of this method of procedure can be demonstrated.

The importance of this and similar papers mainly lies, of course, in the fact that they demonstrate the possibility of damage to reinforced concrete structures such as buildings, bridges, etc., due to stray currents from railways or from other sources. That such possibility exists has been amply proven by laboratory experiments and it becomes a matter of importance to determine whether or not such damage is likely to

Digitized by Google

occur in practice, and if so, to seek the most suitable remedy. Numerous cases of damage to reinforced concrete buildings and bridges have been reported during the last few years, in which the damage has been attributed to electrolysis. We have had occasion to examine a number of such cases and in every case thus far investigated there has been evidence that stray currents had little if anything to do with the deterioration of the concrete. That the damage is in some cases due to corrosion of the reinforcing material by local galvanic currents there can be no question, and in a sense therefore it may be said to be due to electrolysis, but in each case a careful examination has convinced us that stray currents from railways or other power circuits could not be held responsible for the trouble.

It should not be inferred, however, that cases of damage due to stray currents do not exist or may not occur. The laboratory experiments of numerous investigators have shown that such damage may result if conditions are favorable, and thorough investigations should be made to determine whether or not such conditions often arise under actual conditions. But until such cases are found and it can be shown beyond doubt that stray currents are responsible for the damage it is best that we be cautious about drawing conclusions based solely on laboratory experiments lest we create unnecessary alarm among builders and property owners and work an injustice to electrical interests already somewhat overburdened with troubles arising from electrolysis. The work has reached a stage which calls for extensive investigations in the field to determine precisely the magnitude of the danger. Such investigations are now being carried out by the Bureau of Standards.

E. W. Stevenson: I would like to ask the last speaker, if he saw a recent report in the *Engineering News* which described the effects of electrolysis on a whole building, including the foundations, ceilings and every story, where the stray currents were being dissipated. The building is a new one, the business is that of a cold storage packing house, and it is situated within about 300 ft., I think, from the power house of a traction company. Several investigations have been made by different companies, but this was the first public report as to the actual results of this electrolysis.

Of course it was presumed that it was the traction company's current doing all the damage, an engineer was called in by the traction company, and he proved, apparently to the satisfaction of both parties, that the current used by the traction company had nothing to do with it and the destruction was due to the cold storage company's own electric light plant. The engineer's proofs appear to have been very simple for he merely connected two voltmeters with the steel structure of the building, taking the other sides, in one case to the track of the trolley company, and the other instrument to the mains of the company's own electric light plant. Then by manipulating switches in each

Digitized by Google

circuit, he proved to the owners of the building that it was their own current and not the stray currents from the trolley system, which was doing the damage.

All who have anything to do with installation of electric wires in buildings, are aware of the strict rules governing every part of the Board of Fire Underwriters. And it seems to me almost impossible for any inspector of this department, to have passed such an installation before the current could have been turned on. For if the exposure of the situation is correct, the circuits must have been grounded all over the buildings.

What I would like to know is this: How would it be possible to prevent a similar occurrence, supposing that the conditions were the same? For there are not many people who would look for such disintegration of their buildings, unless they were experienced in it.

Speaking from my own personal experience, the company I am connected with, recently erected a building as an addition to their plant. The basement is constructed of reinforced concrete, and just out of curiosity a few weeks ago, as I happened to have a low-reading voltmeter, I tested to see if there were any currents escaping from the trolley rails, which run past the building, to the columns of the structure. I found when a car was passing, a pressure rising from ½ a volt to 2 volts. The needle was deflected till the car got past and for about a mile further, when it gradually came to rest. I had no method of obtaining the quantity of current, but the local traction promised to look into the matter at once and to remedy it.

G. D. Shepardson: We are likely to make ourselves more trouble than is necessary over this question of electrolysis, because, in so many cases the corrosion which occurs is due to a purely chemical action, or to local action on account of non-homogeneous composition of the metal. I presume that many of us have had cases brought to our attention of trouble, apparently caused by electrolysis, where it could be shown, at least to the satisfaction of interested parties, that the trouble might have been caused by non-electrical causes, or at least by purely local currents. So it seems to me that we should guard ourselves against too much alarm on account of stray currents coming in from outside. In short, other sources of trouble may come in which will relieve the railway companies from responsibility.

A. S. Langsdorf: About four years ago, I published the results of a series of experiments on this same subject, and in general they confirmed those which Professor Magnusson has reported here. I did not go quite so far in an attempt to prevent the corrosion as he has done, but confined the work to a study of what would happen if the current passed through the concrete specimens. It was found that even with a very small current, 2/100 of an ampere, the damage was just as great, if allowed to continue, as with much heavier currents for a shorter time; but

Digitized by Google

the question that arises is whether, under actual conditions, with structures buried in damp soil or water, there is likely to be any voltage of sufficient magnitude to force through the current that could do the damage that the 2/100 of an ampere did in the case of my specimens. The apparent resistance of the specimen, after the action has gone on for a short while, is very high, due, no doubt, to polarization that takes place; it amounts to about 500 or 600 ohms per specimen, with a thickness of 2½ or 3 in. of concrete; and that means that the voltages that are likely to be found in practice due to stray currents from railways, say, perhaps, from one volt up to a maximum of 10 or 12 volts, are hardly large enough to produce a current of destructive magnitude. With reference to what Professor Hoadley has just said, it may be of interest to remark that after I explained the results of my work to the Engineers' Club of St. Louis, the engineer of the Board of Education took the opportunity, in the construction of the concrete footings of a new school building, to bond the reënforcement in such a way that if current did get in from a neighboring street car track, it could get out again without going through the concrete. That is the only case of the kind to my knowledge where concrete footings have been bonded in that way.

George A. Hoadley: Since it seems to be evident, from the proof that we have had, that there is a kind of disintegration taking place in concrete due to the passing of the current from the iron to the concrete or from the concrete to the iron, I want to ask Professor Magnusson whether it would not be possible for the construction companies to so arrange a metallic bi-pass with the inside imbedded iron that the current could be shunted around the concrete? It seems to me that a shunt circuit could be provided that would take care of this.

Maxmilian Toch: C. Edward Magnusson and G. H. Smith's paper on the "Electrolytic Corrosion in Reinforced Concrete" is a welcome dissertation to the literature on the subject. They have mentioned me as one of the earlier investigators on this subject, but since I began these investigations 10 years ago, a dozen or 15 excellent papers have been written on the subject, all of which tend to throw light on it.

What I established was

1. That there is such a thing as electrolytic corrosion.
2. That corrosion always takes place at the anode.
3. If pressure of surrounding concrete is less than the pressure exerted by the formation or the conversion of iron into iron hydroxide, the concrete is bound to split.
4. That no corrosion can occur if a suitable insulating paint be used, which

A. Must be proof against the action of alkali.
B. Proof against the action of water.
C. Of such composition that concrete will adhere to it.

Shaffer has shown that the strength of the currents with which

Digitized by Google

he worked, and which in some instances were so weak that water could not be dissociated by them, produced corrosion just the same.

It must be understood that I am only a quasi-instructor on the subject of the chemistry of paints, but in former years I was frequently consulted on matters pertaining to corrosion, outside of my regular business, and during such consultations I was informed and saw where much damage had been done. I recall one case particularly, where huge pieces had been eaten out of the side of a steel bridge. The corrosion was not chemical in the true sense, but was electrolytic, and the damage was done entirely by both a voltage and ampereage of less than 2.

Messrs. Magnusson and Smith make a statement that I have worked on this problem and have prepared a special paint. I refer to test No. 22, *two coats of Tockolith and one coat of R. I. W.*, No. 110; electrolyte, salt water; time in circuit, 124 days; average volts, 107; showed no evidence of corrosion. This is the only test in the entire lot made by the investigators which shows that the paints in question insulated perfectly. Every one of the other paints used shows a leakage, which indicates that the insulating properties are not as good as the test just mentioned. I dislike to criticize the tests that have been made, because the work deserves great commendation, but the voltage and ampereage are entirely too strong, for whenever electrolytic corrosion takes place, either through induction or through some leaky wire, both the e.m.f. and the current values are usually less than 2, and the surprise to me is that any paint should stand at all a voltage of 107 for 124 days.

I made an examination of some grillage beams which had been coated with these same paints and placed in salty concrete, and after five years, when the grillages were uncovered, the paint was still intact and there was no evidence of corrosion.

What Magnusson and Smith have shown with reference to red lead, graphite, and, in fact, all paints in which a linseed oil varnish is used, is not new, but deserves the careful consideration of every engineer who still uses linseed oil paints on structural steel, for, even if there is no electrolytic corrosion, or any danger of it, alkaline moisture tends to destroy paint completely in which the binder is *oil*. Excellent work on this subject has been done by Mr. G. B. Shaffer.

It is to be hoped that Messrs. Magnusson and Smith will continue their researches, the next time with weaker currents, and also with cements that are waterproof and that contain broken stone, so that a fair comparison can be made as to the action in concrete. It would be well to try out the waterproofing compounds on the market which are added to the cement, and the waterproof coatings which are often applied after concrete has set.

Guy F. Shaffer: This series of tests, on a subject of such vital interest to concrete firms, structural, bridge and electrical engi-

Digitized by Google

neers, railroad companies using electric motive power and street railway companies, should bring forth the fullest discussion as to the limits of investigation in theoretical work of this character. It is the object of the writer to define, from one point of view, some of the limitations and give reasons for such definition.

A. *Stray Currents.* The first factor in the problem is; at what stray current voltage will corrosion of ordinary unstressed steel occur? Now by "stray currents" an upper limit is usually defined in the neighborhood of 15 volts. Even lower voltage drops should be secured with correct electrical installation, but any thing above that must be considered a decided "leak". Therefore any test which is carried above that limit is forcing conditions on the concrete which are not likely to remain long undiscovered in any electrical circuit. It is current flowing at lower and less likely to be discovered voltages that need study. The writer has published a report on a test to destruction at 3.4 volts and unless investigators wish to spend months in useless duplication, no further tests should be made above that limit. To add further data to this point let me say that other tests have just been completed in the laboratories of the Massachusetts Institute of Technology showing that at 1.1 volts corrosion will occur, but these tests were not carried to destruction.

Outside the question of inhibiting or minimizing stray current corrosion by waterproofing or other specially applied methods, this voltage drop is dependent upon several variables:

1. The thickness of the concrete.
2. The per cent proportion of salt solution in the surrounding electrolyte.
3. The density of the mass (involving the proportioning of ingredients).

With a decreasing voltage these factors simply reduce the amount of current flowing, but it is the law of the change in the *rate of corrosion* of imbedded steel which a careful study of these variables would define.

B. *Ingredients in Concrete.* Another factor is the kind of cement, involving as well the kind of stone. This question brings up the discussion of the cause of failure in the concrete. If the action going on is simply an accumulation of rust, and nothing more, the problem of the ingredients vanishes. A test with a non-corrodible anode, such as an arc light carbon, would give some data on that question. But, if there is a chemical reaction going on in the block itself, the chemical nature of the cement and the chemical nature of the stone should be known. Under this head the fact should be pointed out that what should be studied is *concrete* as "Concrete" not as cement and sand.

C. *Imbedded Metal.* Another factor is the kind of steel, iron or other imbedded metal used and the stress to which it is subjected. The question of stress involves not only the stress on the metal, both internal and applied, but stress in the concrete

Digitized by Google

as well. Before the bars are imbedded or tested in any way electrolytically their mechanical and chemical properties should be known, as these properties may have a decided effect on the results, which effect would only be brought out by careful comparative experiments.

A complete study of the three factors outlined above, developed in such a way that the results given are comparable with other experimental data, will determine very closely the law of imbedded corrosion.

D. *Prevention.* A fourth factor is the question of prevention and under this head should be studied all the typical waterproofing compounds and iron preservative paints so that no question of commercialism enters into the application of the results. Now to examine critically the work done by Messrs. Magnusson and Smith as it comes under these several heads.

Under A: Every test reported was carried on at such a high voltage that the five factors they name as involved, (*a*), (*b*), (*c*), (*d*) and (*e*) were distorted out of their true relation to the practical side of the problem.

The ohmic resistance across the cement and sand should have been reported both before and after the blocks were put in circuit.

If by "Fresh Water" (mentioned in Table No. 2) is meant the river or lake water the tests are not comparative as the per cent of impurities should be definitely known.

The mass was not examined as to density.

Under B: Report is given as to the brand of cement and its mechanical properties, but no chemical analysis is given.

As no stone was used the question of "concrete" is immediately eliminated.

Under C: Not only was the iron not reported on chemically, but no report is given as to the weight of the imbedded bars in order to determine the variation in the rate of corrosion from the well defined electro-chemical law of 1.045 grams per ampere hour.

Under D: The report on waterproofing and paint tests is interesting and valuable to engineers, but it narrows some of the results down to a basis that is unfair commercially. If time was lacking for general tests on iron preservative paint films no specific report should have been published as this is unfair to other manufacturers who may have materials equally as good as those described.

The specific resistances of cement and of cement and sand as given are valuable.

One other test not commented on is the test on the crushing strength of blocks *after* being subjected to current. There may be such a question as *recovery* occur so that blocks should be subjected to a coincident current and crushing test.

A general summary of this criticism then is that according to the report of these investigators a great amount of needless duplication is being done. It is hoped that a broader view of the variables of the problem is being studied in the work shown in Fig. 1 and Fig. 4.

Digitized by Google

The writer feels that the subject needs all the study that men of an investigative turn of mind can give, but the wide range of variables must not be lost sight of, as otherwise the data developed will be useless.

Harry Barker and W. L. Upson: The paper by Messrs. Magnusson and Smith has special interest at this time, as there has recently been published[1] the details of a case where the heretofore vague fears of engineers have become quite definitely realized.

The writers, in this discussion, first desire to call attention to the conditions of the structural failures in this building and to point out certain ways in which prevention of trouble in similar cases may be secured. Secondly, there is one point in the studies of Messrs. Magnusson and Smith which may be critically examined. Thirdly, the writers desire to place on record the results of certain studies which have been made during the past year at the University of Vermont, which seem to throw additional light on the mechanism and seat of the action which leads to the disruption of concrete surrounding iron and subject to electric current.

The destruction described, in the article referred to, was in a reinforced-concrete packing house where there were various rendering processes going on which liberated great amounts of vapor laden with organic acids. These condensed on the concrete walls and ceilings and on any cold metal exposed. The 110-volt, direct-current lighting circuits were run in ordinary metal ducts unconcealed and held in contact with the steel reinforcement of the beams and girders by special sockets and bolts. Under the severe conditions which prevailed the concrete became water-soaked and the moisture even penetrated the conduits. Evidently the insulation of a negative wire at one point and of the positive wire at some other point broke down so that current could flow to the reinforcement in one place through the concrete mass to the reinforcement and positive lead in another place with corrosion and disintegration wherever it left the reinforcement. Beams and girders were cracked and the grip of the reinforcement was loosened for some 60 per cent of the total span of each. The original design of the structure appears not to have been very economical, which perhaps was the salvation from complete structural failure. There was a considerable length of beam (40 per cent) near the supports, which was apparently unaffected and this was where the greatest bond stress would be imposed by normal loading. Tests showed no abnormal deflection up to 125 per cent normal load and it was decided to patch up the old beams for service.

Certain preventives of such troubles suggest themselves to electrical engineers and among them may be noted (1) the use of strictly marine installations of lighting circuits where bad

1. *Engineering News*, June 8, 1911. "Serious Injury to a Reinforced-Concrete Building by Electrolysis."

Digitized by Google

moisture conditions prevail; (2) practical insulation of the conduits from the reinforcement of the building, and (3) prevention of water-soaked walls and ceiling by covering with a waterproof membrane like water-repellant paint, etc.

Messrs. Magnusson and Smith seem to conclude from their studies that there is no diminution of the strength of concrete, or mortar, due to the mere passage of current as contrasted with some mechanical action at the oxidized electrode.

In the experiments where the blocks were enclosed in a glass box and fed with brine, certain masking conditions are at once recognized. The strips must necessarily have been loose so that there was a layer of electrolyte all over the outside of the blocks, forming a path for the current in parallel with that presented by the blocks themselves. Indeed, the authors remark that they hoped to secure "a minimum by-path for the current outside the cubes." It is worth while comparing this by-path with the resistance of the cubes themselves.

From the uneven surface of the cubes and the easily broken edges which usually become slightly rounded, it is probable that the liquid layer between each glass plate and the cubes would not be any less than the equivalent of 1/64 in. thick. The four sides in parallel would form a path of salt solution 1/16 in. thick, 2 in. wide and 8 in. long. The resistance of this, according to the figures given by Messrs. Magnusson and Smith, would be 1,390 ohms, using the value for fifth-normal sodium-chloride solution. The resistance of the concrete-block path works out, following the same data, to be 3,540 ohms. The combination of these parallel resistances should result in an apparent resistance between electrodes of 1,000 ohms. Compared with this we find that the resistance between plates was as low as 1,250 ohms, which in a general way confirms the assumption. Polarization voltages have been neglected. We may reasonably suspect that only about a third of the current went through the concrete blocks. This reduces the actual density in the concrete to such a low figure that, in the short space of time covered by the experiments, no diminution of strength was apparent. The iron oxide formed seems to have traveled with the current along the outside of the cubes and not to have penetrated the concrete. This is, in itself, an evidence of the masking phenomena. It also prevents a study of the mechanical effect of the molecules of iron oxide inside the concrete.

Those experiments by Magnusson and Smith, relating to the protection of iron against corrosion, are very useful though they show no practical remedy. It is seen that most of the protective paints depend for their effectiveness on their imperviousness. When, in the course of time, this quality disappears, the protection ceases. It is surprising perhaps that the experimenters did not use also paraffine, which comes the nearest to being truly non-porous, though, of course, it is not a practical paint or coating for such work.

Digitized by Google

The necessity for the greatest possible natural bond between the concrete and reinforcing steel needs to be borne in mind in considering the practical use of these insulating paints. Their use will not be entertained for reinforced-concrete structures by designing engineers. The other remedies of (1) keeping the concrete fairly dry; (2) isolating it from ground waters, and (3) preventing random electric potentials upon steel or concrete, must be relied upon, and so far as present rather academic experiments and practical experience go there is little or no danger to be expected if these conditions are satisfactory.

The University of Vermont Experiments. Two series of experiments were planned by the writers a year ago and now have been carried out (under their general supervision and with the assistance of Professor J. W. Elliot), by Messrs. O. J. Olgiati and H. Roberts, senior students in the departments of electrical and civil engineering, as their bachelor thesis. The series were outlined in the manner hereinafter shown, after having followed the progress of such experiments for several years and with the belief that added light could be thrown on certain obscure points.

For instance, Mr. U. J. Nicholas, in describing[2] experiments carried on at the Massachusetts Institute of Technology found that specimen blocks could be cracked irrespective of the direction of current—whether the central imbedded electrode was anode or cathode. These tests added a little to our knowledge in that they indicated that the cracking of the concrete was due perhaps more to the indirect localized heating or to the mechanical action of disseminated rust. This left us to guess whether the softening and very general disintegration was due to the electric current or to some secondary chemical reactions of the iron, or to mere mechanical stress.

Professor A. S. Langsdorf, in 1909, added[3] to the corroborative evidence then accumulated. Progressive corrosion of imbedded steel was shown; all specimens developed cracks and some showed soft disintegration; a coating of rust developed on the walls of cracks.

Eltinge and Beers have described[4] certain experiments carried on at the Rensselaer Polytechnic Institute in which they duplicated the cracking and soft disintegration of electrolysis by externally heating the projecting end of the imbedded bar.

The first series of tests planned by the writers was intended to be wholly qualitative and using the studies already mentioned as points of departure. Several points should be specifically noted.

1. Collapsible iron electrodes, shown in Fig. 2, were used in the hope of showing whether or not local thermal expansion, or the demand of the oxidized iron for more room at the electrode

2. *Engineering News*, December 24, 1908.

3. *Journal of the Association of Engineering Societies*, February, 1909; Abstracted in *Engineering News*, April 29, 1909.

4. *Engineering News*, March 31, 1910.

Digitized by Google

surface would crush the electrode instead of cracking and softening the concrete.

2. The use of imbedded carbon electrodes, in one set of specimens, was tried to study the effect of eliminating iron and iron oxide.

3. By using loose carbon electrodes the effect on cracking, of eliminating the mechanical forces at the electrode surface and the iron oxides in the concrete, was studied.

4. Duplicate specimens with these several types of electrodes were to be subjected to alternating current, keeping all conditions, except the kind of current, the same as in the direct-current tests.

5. Special specimens were subjected to thermal stresses according to the temperatures actually noted in the other trials.

All of the specimens, except two, were of the same general shape and make-up except as noted. Fig. 1 shows the arrangement with iron pipe, and Fig. 2 shows the collapsible electrode used in its place.

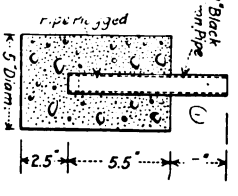


FIG. 1

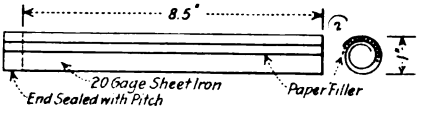


FIG. 2

"Ironclad" brand Portland cement was used and the quality-test results compared well with the specifications of the American Society for Testing Materials as shown in Table I.

TABLE I.—QUALITY TESTS OF "IRONCLAD" CEMENT USED IN UNIVERSITY OF VERMONT ELECTROLYSIS EXPERIMENTS

Fineness:

Left on 200 sieve 23.80 per cent
Left on 100 sieve 5.85 per cent

Specific Gravity:

$$\frac{\text{Weight cement in grams}}{\text{Displaced volume in cu. cm.}} = \frac{65}{20.6} = 3.11$$

Breaking Strengths,

Neat cement briquettes:

Days age	No. 1	No. 2	No. 3	Average
7	480	550	588	539
28	625	645	667	646
1:3 Sand-cement mortar:*				
7	90	95	107	97
28	185	190	103	159

*The low breaking strength of the mortar was probably due to the excessive dryness of the sand.

Digitized by Google

The sand used in all tests and experiments was of uniform size, passing through a 10-mesh and remaining on a 30-mesh screen, and was thoroughly dry. The aggregate was ½-in. broken gray sandstone, very dry. The specimens subjected to current were of a 1:2:4 mixture of cement, sand and stone. In all, 28 specimens were made for these qualitative studies, six with each of the four types of electrodes and two of each special type shown in Figs. 3 and 4.

The specimens were connected in series-parallel circuits, as shown in Figs. 5 and 6, to facilitate regulation of the current. Each group contained one block with each type of electrode.

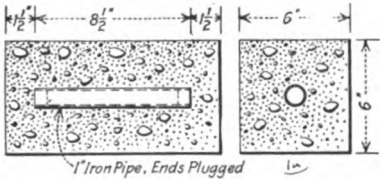


FIG. 3

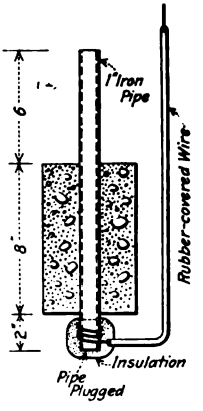


FIG. 4

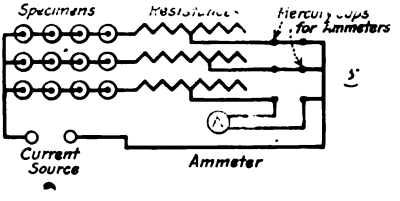


FIG. 5

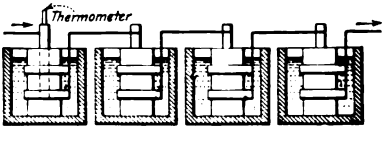


FIG. 6

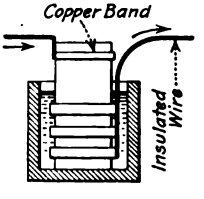


FIG. 7

Two duplicate tests were run simultaneously, one with alternating and one with direct current. Current was regulated several times a day to the value of 0.1 ampere. A small generator set was used for the direct current and the city-supply system for the alternating current.

To determine temperature effects, the special specimens, shown in Fig. 4, were tested with the others. They were placed in water as in the electrolysis experiments, but the current was confined to the metallic circuit and regulated to secure the same temperature of a thermometer in oil in the pipe as in the electrolytic runs. The temperature found in the latter

Digitized by Google

runs were so low that a current of 0.1 ampere through the pipe of the temperature specimen was enough.

For simplicity, the results will be presented separately for each type of electrode.

Solid Pipe. The behavior on direct current was in accordance with results of other experimenters. When current was first turned on, there was an evident washing out of cement or apparently similar materials, with the evolution of much gas at the imbedded electrodes. At the end of 24 hours a notable amount of iron oxide had been forced out around these electrodes. After a few days the entire top of the specimens, which were out of water as shown in Fig. 6, was covered with oxide. During the experiments gases were given off more or less from all parts of the concrete. The average centigrade temperatures were as shown below:

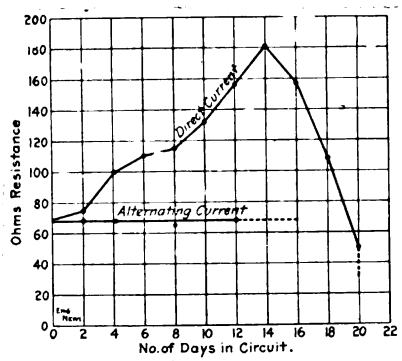


FIG. 8

Room	Thermal test specimen	Direct current set	Alternating current set
22 deg.	22.1 deg.	22 deg.	22.15 deg.

The "apparent" resistances of all blocks were measured by the voltmeter-ammeter method. Table II shows typical results on one set and the data are plotted in Fig. 8.

TABLE II.—RESISTANCE OF DIRECT CURRENT SPECIMENS

No. days	Volts drop	Amperes	Resistance
2	7.5	0.1	75.0 ohms
4	10.0	0.1	100.0 "
6	11.0	0.1	110.0 "
8	11.5	0.1	115.0 "
10	13.2	0.1	132.0 "
12	15.7	0.1	157.0 "
14	18.1	0.1	181.0 "
16	15.8	0.1	158.0 "
18	10.8	0.1	108.0 "
20	5.0	0.1	50.0 "
RESISTANCE OF ALTERNATING CURRENT SPECIMENS			
2	6.8	0.1	68 "
4	6.8	0.1	68 "
8	6.6	0.1	68 "
12	6.8	0.1	68 "

Digitized by Google

The gradual increase in resistance may perhaps be due to the accumulation of iron oxide, decreasing porosity, accumulated gas, or to some chemical change in the cement. It seems probable that the iron goes into solution as a hydrate and is later converted to oxide by evolved oxygen and perhaps by the cement compounds. If the last action was general throughout the mass of concrete, it might be expected to diminish the strength. If, however, the action was confined to the neighborhood of the electrode there might be no appreciable change in the general strength of the concrete mass. The sharp peak of the direct-current resistance curve, Fig. 8, suggests the beginning of mechanical failure.

A specimen on direct current showed distress at the end of 20 days and ruptured, on the following day, so that it could be pried apart with a screw driver. The first indication of failure was the appearance of small drops of colored water on the upper surface of the concrete. These places developed into the cracks

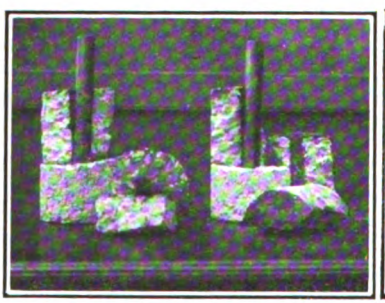


FIG. 9

FIG. 10

along which the blocks broke. As expected, the iron was considerably corroded and the rust disseminated throughout, though more marked along the line of failure. The concrete itself could easily be broken with the fingers.

The specimens subjected to alternating current did not break at low current density, nor was there any corrosion of the electrode. The appearance of the concrete and general strength were not changed. No gas was liberated by the current, and it was not manifest by other signs. At the completion of the tests alternating current of up to 3 amperes was sent through the blocks. At 2 amperes the internal temperature increased to 45 deg. cent. and the blocks split after being in circuit 8 to 10 hours. They were broken apart with a hammer and, as seen in Fig. 9, the iron was not corroded. The disruption seems to have been the result of temperature stresses. The specimens with various solid imbedded electrodes behaved similarly, all splitting apparently from the same cause.

Collapsible Electrodes. The specimens with collapsible elec-

Digitized by Google

trodes, on direct current, were the second in order of breaking. This tardiness might have been due in a small measure to slightly larger electrode diameter and probably, to a greater degree, to the yielding of the collapsible electrode to the demand of the oxide for more room. The disruption then might have come finally from the stresses set up by the formation of iron oxide in the pores of the concrete a little distance in from the electrode. On alternating current the collapsible-electrode specimens showed no signs of distress. The concrete was not softened and the blocks did not split on increasing the current to 3 amperes.

Imbedded Carbon Electrodes. It was surprising to find that the behavior of these specimens under direct current was similar to that of those with iron electrodes. In place of iron oxide, a thick black material, apparently a combination of carbon and some ingredient of the cement, was forced up and out around the electrode. The composition of this material was not studied.

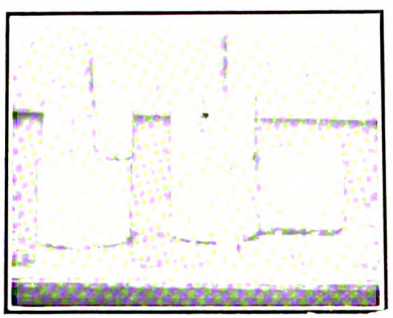


FIG. 11

FIG. 12

The carbon electrode was eaten away and considerable dissemination of the corrosion product was found on prying the specimens apart, as seen in Fig. 12. The increase in resistance of these specimens was not so decided as in the case of iron electrodes. Cracks developed in 25 days. The softening of the concrete was noticeable, but not as marked as with iron electrodes. On alternating current no signs of damage were found. The electrode was not corroded and the concrete was not softened.

Loose Carbon Electrodes. With direct current, gas was freely evolved at the carbon electrode and a decided smell of chlorine noted, though no chlorine salts or other chemicals were added to the water. A black compound was formed, apparently identical with that found with the imbedded carbon electrodes and the electrode was deeply pitted. After being in circuit for some four weeks, no disintegration of the concrete was found. A current of one ampere was then forced through for 12 hr., but without apparent effect. The specimens were broken open with a hammer, and appeared as shown in Fig. 14.

Digitized by Google

On alternating current no ill effects were noted, as may be inferred from Fig. 15.

Completely Imbedded Iron. These specimens were made up to approximate actual construction conditions, where the random potentials might not be actually applied to the reinforcement. The current was led into the concrete as shown in Fig. 7. After 18 days, with 0.1 ampere, direct current, the block split, showing typical corrosion of the iron and dissemination of oxide. The specimen on alternating current was not affected, and is shown, at the left in Fig. 16, after being broken open with a hammer.

Thermal-test Specimen. The steel in this was kept at the observed temperature of the iron-pipe specimen on direct current during the entire run. The temperatures varied but slightly from those of the room and the specimen remained sound. The pipe was not found rusted, on breaking open at the end of the tests.

Quantitative Studies. It was hoped by subjecting a large number of specimens, with the various types of electrodes

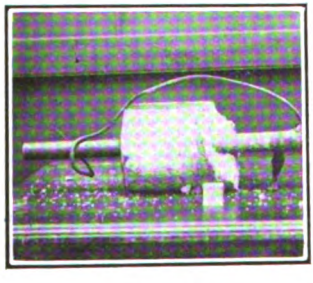


FIG. 13

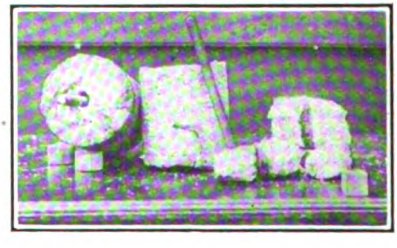


FIG. 14

previously mentioned, to similar treatment, and by breaking samples at regular intervals, to determine whether the destructive actions were gradually developed or suddenly. The specimens were made in standard 4-in. molds and were set under water for three weeks before use. A 1:2 cement-sand mortar was used, the cement and sand being the same as already noted. The current was limited to 0.03 ampere, to eliminate chance of temperature stresses. Fig. 17 shows the general make-up of the blocks, the only difference in the several specimens being in the use of iron-pipe, collapsible iron, imbedded and loose carbon electrodes.

In all, 22 blocks with each of the four types of electrode were made; 20 blocks of each type were placed under current. In addition, 20 dummy cubes, without electrodes, were made and used under same conditions, except as to current. At the start, two blocks of each type were crushed and at regular intervals two more of each type were crushed. The iron-pipe electrodes were weighed before being placed in the blocks and as broken

Digitized by Google

to determine the loss of iron during the test. Even loading in the testing machine was secured by using blotting paper between the block and the crushing heads of the machine. The load was applied at right angles to the direction of electrode axis. The results of the tests are shown in Table III. The electrical circuits were the same as for the qualitative series, in general.

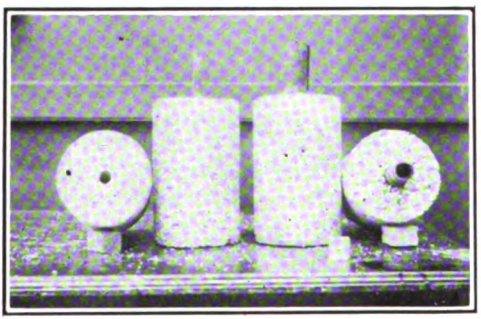


FIG. 15

Conclusions. All these experiments, studied in connection with previous ones, variously noted, allow several tentative conclusions, concerning the seat and mechanism of electrolytic disruption of reinforced concrete. It is to be emphasized that these are only tentative and do not effect any recognized practical

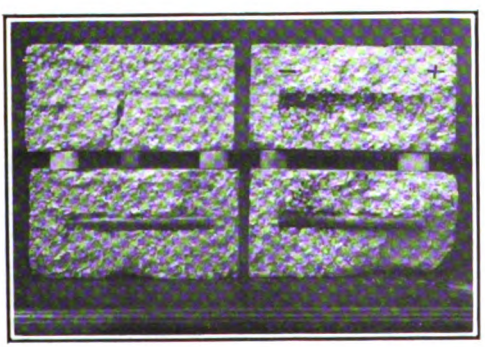


FIG. 16

measures which may be taken to prevent conditions leading to structural failure in the reinforced concrete, as already noted.

1. The disruption of reinforced concrete may result from stresses produced by local thermal expansion where the current density is high, with either alternating or direct current and irrespective of the direction of current in the latter case.

Digitized by Google

TABLE III

RESULTS OF QUANTITATIVE TESTS ON ELECTROLYTIC DISINTEGRATION OF REINFORCED CONCRETE.

Iron-pipe electrodes					Collapsible iron electrodes			Imbedded carbon electrodes			Loose carbon electrodes		
No. specimen	No. hr. in circuit	Average loss per day, grams	Breaking load of specimen	Breaking load of dummies	No. of specimen	No. hr. in circuit	Breaking strength	No of specimen	No. hr. in circuit	Breaking strength	No. of specimen	No. hr. in circuit	Breaking strength
0*a*	0	0.0	20,100		0*b*	0	14,400	0*c*	0	30,000	0*d*	0	14,810
1*a*	66	0.215	19,600	18,070	1*b*	66	14,230	1*c*	66	22,700	1*d*	66	15,000
2*a*	66	0.175	18,680		2*b*	66	12,910	2*c*	66	19,630	2*d*	66	18,000
3*a*	138	0.202	19,550	17,900	3*b*	138	13,670	3*c*	138	25,120	3*d*	138	18,560
4*a*	138	0.178	18,750		4*b*	138	12,800	4*c*	138	25,740	4*d*	138	16,900
5*a*	186	0.194	19,600	20,900	5*b*	186	14,250	5*c*	186	24,250	5*d*	186	22,010
6*a*	186	0.195	24,200		6*b*	186	10,000	6*c*	186	23,800	6*d*	186	19,020
7*a*	282	0.202	20,800	20,320	7*b*	282	14,720	7*c*	282	24,340	7*d*	282	18,450
8*a*	282	0.182	19,950		8*b*	282	13,870	8*c*	282	21,700	8*d*	282	17,180
9*a*	354	0.197	22,630	24,325	9*b*	354	14,800	9*c*	354	23,200	9*d*	354	18,110
10*a*	354	0.203	22,740		10*b*	354	10,460	10*c*	354	17,650	10*d*	354	15,500
11*a*	426	0.211	19,860	23,500	11*b*	426	12,530	11*c*	426	18,350	11*d*	426	16,880
12*a*	426	0.214	19,200		12*b*	426	12,570	12*c*	426	24,000	12*d*	426	15,440
											13*d*	498	19,200
	Test stopped for three days				Test suspended for three days			The test was stopped for three days			14*d*	498	15,300
											15*d*	570	12,000
13*a*	498	0.210	28,710	25,980	13*b*	478	15,590	13*c*	498	33,500	16*d*	570	12,460
14*a*	498	0.198	26,110		14*b*	478	14,900	14*c*	498	32,100	17*d*	642	19,400
15*a*	570	0.197	30,450	27,010	15*b*	570	17,370	15*c*	570	37,250	18*d*	642	16,700
16*a*	570	0.176	28,350		16*b*	570	19,100	16*c*	570	29,250	19*d*	744	19,700
17*a*	642	0.223	20,500	31,300	17*b*	642	18,300	17*c*	642	30,300	20*d*	744	17,650
18*a*	642	0.190	29,600		18*b*	642	18,200	18*c*	642	26,100			
19*a*	744	0.194	36,000	31,245	19*b*	744	12,500	19*c*	744	24,500			
20*a*	744	0.188	27,740		20*b*	744	15,600	20*c*	744	31,700			

Digitized by Google

2. With small current densities and without temperature stresses being developed, disruption finally results from the accumulation of iron oxide at and near the imbedded iron where direct current leaves the iron to enter the concrete.

3. The bursting stresses developed with low current densities are largely caused by the formation of iron oxide, immediately at the anodic surfaces to a slight extent, but largely in the concrete near the anodes, the depth of penetration depending on the porosity of the concrete, the gas pressure, current strength, etc., among other things.

4. No gradual reduction of the strength of the concrete has been shown to accompany progressive corrosion of the iron. The oxygen for the formation of oxide probably is furnished mostly by the electrolysis of water and only to a slight degree is taken from the cement compounds.

5. Disruption may result with low current densities, where iron is not the anode material if other compounds are formed from the anode or from the concrete and expand during the secondary reactions. In all cases, pressure of gases developed may slightly assist or hasten disruption.

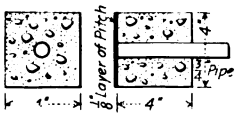


FIG. 17

6. The general softening of the concrete after rupture is similar to that in specimens crushed mechanically and may be here regarded as largely the result of the bursting stresses.

7. A single current of small density may cause corrosion and disruption at several points by passing to and leaving a number of pieces of reinforcing steel, each completely imbedded.

8. With large leakages of either direct or alternating current to reinforced concrete, structural failures may be expected within a few hours of the start of current, and as the result of thermal effects.

9. With small leakages of direct-current an insidious undermining of structural strength must be expected.

10. With alternating currents, when the current density is low enough to eliminate local temperature stresses, repeated tests have shown no danger of structural troubles. This is in accord with the findings reported by Mr. J. L. R. Hayden, before the A. I. E. E., March, 1907, but does not mean that there is absolutely no effect from alternating currents. It would indicate rather that the secondary reactions were so slow that the primary reactions were practically reversed each cycle.

11. Structural trouble is not to be expected with dry concrete unless random high direct-current voltages are noted on the structural members.

12. Present methods of electrical survey seem sufficient to detect dangerous (to the structure) voltages about reinforced concrete structures and remedies are available for application as each individual case seems to demand.

Digitized by Google

DISCUSSION ON "SOLUTION TO PROBLEMS IN SAGS AND SPANS," "SAG CALCULATIONS FOR SUSPENDED WIRES," AND "MECHANICAL AND ELECTRICAL CHARACTERISTICS OF TRANSMISSION LINES." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE AND JULY, 1911.)

(Subject to final revision for the Transactions.)

Paul M. Lincoln: In the paper by Messrs. Pender and Thomson, I notice they lead us through quite a number of equations containing hyperbolic functions, and finally come to our good old friend, the parabola, as representing the curve which a transmission line assumes when it is extended between two supporting structures. The result is one we all recognize, although I must say for myself I do not recognize the process by which it was derived. It is perfectly true that the parabola can be taken as the curve which a transmission line will assume and the error due to this assumption is very small in the ordinary case. The sag must be large in proportion to the span, before the error in making this assumption needs to be taken seriously.

I also notice that Messrs. Pender and Thomson have arrived at results that show that our old and well known method of calculating line drops is perfectly correct for 60 cycle lines up to one hundred miles, and 25-cycle lines up to two hundred miles, and it is not necessary to add the refinements which they have worked out for lines below that length.

In regard to Mr. Thomas paper, I have been impressed and delighted with the way he has worked the thing out. However, I would like to ask one question. Mr. Thomas has assumed that the metal constituting the line has a certain amount of stretch when it is loaded by wind, ice, or in any other manner. It seems evident, however, that he has assumed in his calculations that the supports of the transmission line are absolutely rigid, that they do not give. Now, I do not believe that this assumption is justified, because the bending of the supports, particularly when there are angles in the line, will, I believe, aggregate nearly as much as the stretch in the metal of the conductor. Therefore any results which are deduced upon the stretch of the conductor only, would not necessarily hold in an actual transmission line, particularly when there are angles in the line. We all know that the assumption that the supports of the transmission line are absolutely rigid is far from being a correct one. I ask Mr. Thomas if he has taken any cognizance of this matter of rigidity of supports in working out his theory here?

L. C. Nicholson: Those of us who are in the habit of calculating sags, will be glad to have such a short-cut and accurate method as Mr. Thomas points out.

There is a point which I wish to mention in connection with the sag and spacing of wires. The ordinary understanding that the distance between conductors should be determined largely by the operating voltage is not entirely rational. For such other factors as span, sag, size, weight and material of

Digitized by Google

conductor should be given consideration, and I believe have more direct bearing upon the problem of properly spacing the conductors than has the operating voltage. In the case of extra high voltage lines electrical considerations of course become important.

N. J. Neall: This subject has made a special appeal to me, for I happen to have had actual experience with the problem which the theoretical presentation this morning relates to. I was particularly impressed in this connection by what Dr. Pender said in Boston when he presented in advance the paper written by Mr. Thomson and himself, in explaining that it was all well enough to have rules and methods, but that most engineers use these rules and methods so infrequently that when they came back to the work again they had to brush up on all the facts connected with that method, and waste considerable time in getting started, and so therefore I consider admirable the degree to which Messrs. Pender and Thomson have taken their paper, in finishing the calculations, and giving the one reliable result which may be selected with confidence.

Whereas the papers presented today treat this as a theoretical problem, I think the practical problem necessitates, although it had not been so expressly stated, that every span shall be a self-contained one, irrespective of its shape, that is to say, we do not want to have a span when points of support are at such different levels, that the lower support is just at the lower end of the span or perhaps inside of it, even though it might be argued along the lines suggested yesterday by Mr. Thomas that such procedure might be intended to prevent oscillations.

It is highly important to know where the low point of the span will come with respect to the lower point of support. As a practical proposition you are obliged to limit this to a distance of, say, 50 to 75 feet, as a minimum just to save yourself. There may be line constructions of grades of excellence which will give up to all theoretical requirements, but I doubt it, and it is the practical margin you must be guided by in laying out this data for use. Now, the difficulty is also enhanced by the fact that if your line is 500 miles long, or even 100 miles long, you have a variable topography to accommodate the line to, and it is no uncommon thing to get a very irregular profile. A very useful method of laying out transmission lines is by use of a template. One template is used for the minimum sag without wind and another for maximum sag without wind. Both are of great importance in determining respectively the distance of the bottom of span from the lower point of support, and the least clearance above ground.

Another point that has been touched on in these papers is the effect of adjacent spans of unequal length. On the principle that the line is to have self-contained spans with a uniform stress in the conductor throughout, you must carefully allow for the short span adjacent to long ones; and on down hill work the

Digitized by Google

effect is to take away from the top spans and increase the sag of the bottom ones because of the total gravity effect.

There is, however, one point in this matter of spans which is of great importance to our engineers. This relates to railroad and telephone crossings where requirements may call for construction much in excess of what is theoretically necessary for the line as a whole. Lastly, the imperfections introduced by construction may further seriously impair your line—such for example as bad surface cuts due to improper use of line tools.

The cost of spans and of the various details entering into these, is a very serious item. It is almost impossible to combine a result theoretically, by means of a formula, which will tie cost to the other considerations; but there are modifications, even in these methods, which will be necessary, and the exception which will prove the rule. But, broadly speaking, the literature which has been created in these papers is invaluable, and those who have to deal with these problems should study carefully each of the methods presented, and decide which will be the most useful for his particular purpose.

Jean Bart Balcomb: I very much appreciate the practical remarks made by the last speaker, also the idea of elasticity of support, especially of the towers. I believe these enter into the problem of wire tension more largely than most of us have realized in the past. Referring to the papers specifically, the last sentence of Mr. Robinson's paper reads: " In fact, the stress values approach infinity as the curve of the span approaches a straight line, due to being drawn taut." I wish simply to call attention to the fact that this is universal, whether the supports are level, or one is higher than the other.

While it is always disagreeable to adversely criticize a paper, there is one statement contained in the paper by Messrs. Pender and Thompson which I would like to mention. In speaking of the deflection, the paper says: " To meet this requirement on a long span, especially with aluminum wire, would require a relatively large sag, from 30 to 100 ft., depending on the length of span and size of wire." The paper then goes on to say: " This would require a prohibitive height of tower, at least for level country work, and therefore we should not use it." To my mind, since we are trying to be scientifically exact, we should live up to the facts, even though they are not satisfactory. If we can prove the supposed facts to be wrong, they are no longer facts. I wish to congratulate the authors, not only on the excellence of their exact treatment of the subject, but also for the finished thought they give, and an approximation that will answer in most cases. I think both exact and approximate solutions should be included in scientific papers generally.

My work in the mountains and on the Nevada desert has especially impressed me with problems like these, that are not met with so much in the level country and under ordinary conditions. Going into places where the maximum temperature reaches 140 deg.

Digitized by Google

and where at times the worst conditions of sleet and ice are encountered, these problems are pressed home to one very closely. I might call attention to this—in my experience I have noticed that the maximum sag, wherever there are sleet conditions, is not caused by the maximum temperature, but by the maximum ice conditions at the highest temperature in which sleet will form; so that is the point we need especially to bear in mind when considering how low our wire will hang; also that the maximum stress will be induced by the greatest wind and lowest temperature conditions combined. In approaching these problems I always find it worth while to select a few points that are determinative, then work with these in mind.

A point which has not been touched thus far, I think, is the stress that is produced by the oscillations of the wire while the wind is blowing. In our mathematical determinations, we too often assume that when wind conditions prevail, the wire swings over with the wind and remains at a certain angle; yet the wire instead of doing this, swings back and forth, sometimes with considerable violence. How to arrive at this stress, I am unable to say, but I think the matter deserves very careful study.

As a closing thought—there are some excellent determinations among those offered here this morning, and I would like very much if this Institute another year could have these different formulae compared with the large amount of data, gathered throughout the country, showing actual conditions. It seems to me if some one at the present time could be asked to prepare a paper and present it a year from now, or possibly two years from now, it would be worth while and would be greatly appreciated by engineers.

The above applies to the mechanical side especially. Regarding the electrical end of the work, I think we are in a transitional period and the next few years will show large development—so we are in position to study, but not to determine, these electrical factors for perhaps a number of years to come.

W. L. R. Robertson: I have studied Mr. Thomas' paper carefully and with much interest. He is to be commended for the introduction of the so-called stretch curves. The "curves" are nominally straight and parallel lines, they can be readily computed and plotted, therefore, shortening somewhat the process of calculation when temperature and stress are considered.

As a matter of fact, this stretch curve is in principle identical with the so-called hypothetical curve given in my paper; the only difference being in the selection of coördinates. When plotted between stress and length of arc, the curve is the nominal straight line. When plotted between stress and sag it is a curved line. In theory the stretch curves plotted between stress and length of arc are not entirely straight nor parallel. I would like to ask Mr. Thomas whether there are any conditions where the use of perfectly straight parallel stretch curves would introduce undesirable error? When the stress passes the elastic limit, the

Digitized by Google

stretch curve is decidedly a curved line especially for annealed copper.

I have heard of a method of erecting wires which may, or may not have merit: Namely, the use of annealed copper wire erected more or less taut and allowing the weather conditions to stretch the wire until it has sufficient sag to withstand all conditions of load, and never taking up the sag. As the wire stretches it probably increases in tensile strength.

For investigating or determining the extent of the merit of such a method as this, or for investigating any other condition where it is required to calculate beyond the elastic limit, the straight line stretch curve is of no value.

If one half of the ultimate strength or 1,700 lb. per sq. in. is the allowable stress for annealed copper and this is finally considered to be good engineering, then calculations must be made beyond the elastic limit and it is only the true hypothetical curve that can be used.

Further after one becomes an adept in the use of these solutions they will really find that the application of the true hypothetical curve involves but very little more calculation than the straight line stretch curve especially if very closely approximate results are all that are desired.

It seems to me that the most vital point to be considered in sag and span is the behavior of the material used in the span. By behavior I mean the relation between strain and stretch, permanent set, tendency to increase in tensile strength upon stretching, temperature changes, etc. That is why more data on wires than we have today is desirable.

Problems involving all of these properties can only be investigated by so-called true stretch or hypothetical curves.

There are a few emphases which I would like to make relative to the claims set forth in my paper, namely, the solutions are intended to be universal, to apply to abnormal as well as normal conditions; to apply to any material; to take care of any such conditions of poles swaying, cross-arms twisting, etc., and to give mathematical correct results with a minimum of additional calculation.

H. F. Thomson: I would like to refer merely to the point made by Mr. Neall in the discussion, in that we have endeavored to put too much of the solution on the charts, and the discussion which accompanies the chart is more of a justification than anything else; that is, an engineer could cut out the charts included in the paper, and with the suggestions made at the bottom of the chart, could work out a complete example without any additional help from the paper itself, and the discussion merely goes to broaden out the points which are included.

H. V. Carpenter: In adapting tower construction to the use of suspension insulators convenience has probably been the reason for arranging the three conductors of a circuit in a vertical plane as has been done in a number of prominent cases. Ex-

Digitized by Google

perience has brought out the fact that this construction must be used carefully in localities where sleet forms, as it has been found that when a heavy load of sleet suddenly falls from one span while the adjacent spans retain their loads the lightened span may rise into contact with the wire above it.

If we remember that the vertical load on any insulator is only $\frac{1}{4}$ to $\frac{1}{8}$ of the tension on the cable, it is clear that a small percentage of unbalance in the tensions on either side of an insulator may deflect it considerably. Since a small change in the position of the end supports of a span causes a very large change in the sag it can be seen that the trouble described above will be more likely to occur than would be anticipated.

A simple example will show what may be expected. Assume a circuit of 0000 copper strung with 600 ft. spans and 8 ft. vertical spacing, hung on suspension insulators 21 in. long. If the sag is 3 per cent when loaded with $\frac{1}{2}$ in. of sleet (no wind), the tension will be about 3,200 lb. total. If all the sleet on one span should fall before any on adjacent spans, the sag of the lightened span will decrease to approximately 1.6 per cent or the middle of the cable will rise about 8.4 ft., giving a permanent short circuit with the cable above. This involves a deflection of about 33 deg. of each insulator from its normal vertical position.

On account of the elastic character of the entire structure much smaller disturbances than that assumed would be sufficient to cause a momentary throw of a cable that would cause trouble.

Hugh Pastoriza: The chart given by Mr. Thomas offers a very easy method for computing line stringing curves but it may also be applied conveniently to other mechanical problems of transmission lines.

For example, certain types of line crossing embody an auxiliary guy which catches and supports the span wire when it breaks at either insulator. In order to get proper clearances under the broken span wire, its final sag after breaking must be determined. Here Mr. Thomas chart is of considerable assistance. From the mechanical construction of the crossing span, the increase in length of wire between supports, when the span wire breaks, can be found. Expressing the new length in per cent of the span, the new tension and deflection may be read from the chart. This neglects change in length due to reduction in tension, but an approximate correction may easily be made for this.

Problems connected with flexible transmission structures require the use of a curve between tension in span wire and deflection of support. This curve may be found for any given case from Mr. Thomas' chart. Starting with normal tension and deflection and span length, the new tension and deflection as supports approach each other by 0.1 per cent of span for example, may be found approximately by obtaining from the curves the tension and deflection which would obtain on the original span but with a length of span wire 100.0/99.9 of the original. A

Digitized by Google

correction may also be applied here for change in wire length due to change in tension.

R. S. Brown: The calculation of the long transmission line may be simplified considerably by the use of the relation between inductance and capacity:

$$L\,c=\frac{1}{V^2}$$

where V is the velocity of light. This would be rigidly true were it not for the effect of the magnetic flux within the wire. In the actual case the approximation is very close if a reduced value of the velocity of light is used, (183,000 miles per second). Within the range of commercial sizes of nonmagnetic wire, the maximum error thus introduced in the value of capacity is one per cent. By the use of this relation one variable, line capacity, may be eliminated from the problem.

The following symbols are used:

P = The real power at the receiver.
E_0 = the receiver voltage (taken as standard phase).
$\dot{E}$ = the generator voltage.
I_0 = the load current.
φ = power factor angle of load.
ω = 2π frequency.
l = length of line, miles.
r = resistance per mile of line.
c = capacity per mile of line.
L = inductance per mile of line.
x = reactance per mile of line.
$\dot{z}$ = impedance per mile of line.
$\dot{y}$ = admittance per mile of line.
$R = l\,r \qquad X = l\,x \qquad \dot{Z} = l\,\dot{z} \qquad \dot{Y} = l\,\dot{y}$

Dotted letters represent vectors.
Undotted letters represent reals.

The general equation of the long transmission line as given in Steinmetz's Engineering Mathematics is:

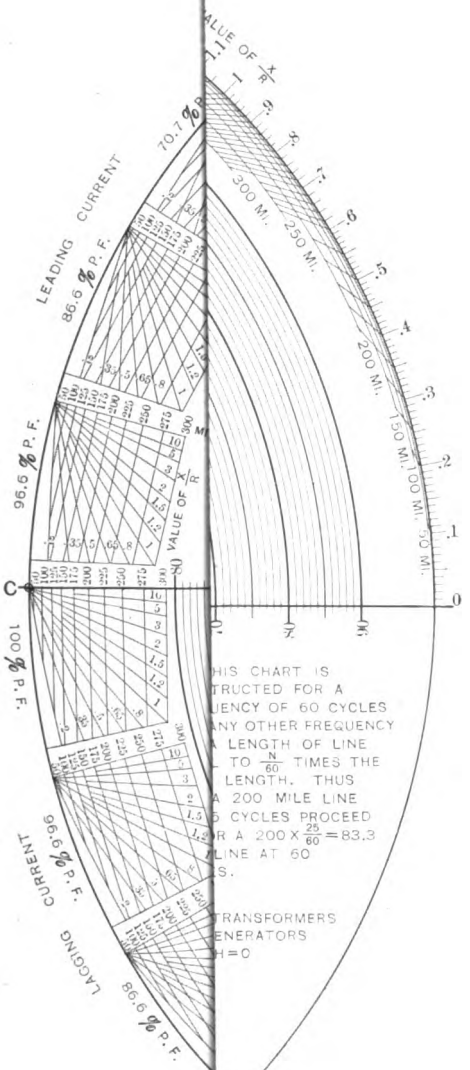
$$\dot{E}=\dot{E}_0\,\dot{A}+\dot{I}_0\,\dot{B}\,\dot{Z}$$

Where $\dot{A}$ and $\dot{B}$ are vector functions of line constants as follows:

$$\dot{A}=1+\frac{\dot{Z}\,\dot{Y}}{2}+\frac{(\dot{Z}\,\dot{Y})^2}{24}+\ldots\ldots$$

$$\dot{B}=1+\frac{\dot{Z}\,\dot{Y}}{6}+\frac{(\dot{Z}\,\dot{Y})^2}{120}+\ldots\ldots$$

Digitized by Google



Digitized by Google

(R. S Brown)

cor
to
ma
ind

wh
it n
act
the
the
err
By
clin
Stei

W

Digitized by Google

$$\dot{Z}\,\dot{Y} = l^2\,(r + j\,x)\,j\,\omega\,c$$
$$= l^2\,(j\,r - x)\,\omega\,c$$

This assumes $y = j\,\omega\,c$, that is, zero leakage. By means of the relation,

$$L\,c = \frac{1}{V^2}$$

$$\dot{Z}\,\dot{Y} = l^2\,(j\,r - x)\,\omega\,\frac{1}{L\,V^2}$$

$$= l^2\,(j\,r - x)\,\frac{\omega^2}{x\,V^2}$$

$$= \left(\frac{\omega\,l}{V}\right)^2 \left(j\,\frac{r}{x} - 1\right)$$

Dividing equation 1 by E_0

$$\frac{\dot{E}}{E_0} = \dot{A} + \frac{\dot{I}_0}{E_0}\,\dot{B}\,\dot{Z}$$

$$\frac{\dot{E}}{E_0} = \dot{A} + \frac{P}{E_0^2}\,(1 + j\tan\varphi)\,\dot{B}\,\dot{Z}$$

$$1 + j\tan\varphi = \frac{\sigma^{j\phi}}{\cos\varphi}$$

$$\frac{\dot{E}}{E_0} = \dot{A} + \frac{P\,\dot{B}\,\dot{Z}}{E_0^2\cos\varphi}\,\sigma^{j\phi}$$

$$\frac{\dot{E}}{E_0}\,\sigma^{-j\phi} = \dot{A}\,\sigma^{-j\phi} + \frac{P\,\dot{B}\,\dot{Z}}{E_0^2\cos\varphi}$$

Digitized by Google

The regulation is defined as $\frac{E-E_0}{E_0}=\frac{E}{E_0}-1$ and the magnitude of $\frac{\dot{E}}{E_0}=\frac{E}{E_0}$, is the length of the vector $\frac{\dot{E}}{E_0}\,\sigma^{-j\phi}$. This length is the distance between the terminii of the two vectors $-\dot{A}\,\sigma^{-j\phi}$ and $\frac{P\dot{B}\dot{Z}}{E_0^2\cos\varphi}$.

The terminus of $-A\,\sigma^{-j\phi}$ is plotted at the left of the chart, it being a function of φ, x/r, and l.

The second vector is

$$\frac{P\dot{B}\dot{Z}}{E_0^2\cos\varphi}=\frac{P\dot{B}Z}{E_0^2\cos\varphi}\,\sigma^{j\tan^{-1}\frac{x}{r}}$$

The part $\frac{PZ}{E_0^2\cos\varphi}$ is real and it must be multiplied by the vector part $\dot{B}\,\sigma^{j\tan^{-1}\frac{x}{r}}$ whose terminus is plotted in the first quadrant on the chart. The length of vector $\dot{B}\,\sigma^{j\tan^{-1}\frac{x}{r}}$ can be scaled from the chart but is most easily found from the small curve in the fourth quadrant it being practically independent of $\frac{x}{r}$. It is designated by κ.

The length $\frac{\kappa ZP}{E_0^2\cos\varphi}$ is laid off in the proper direction as determined by a line joining the origin with the intersection of appropriate curves in the first quadrant, and the distance from the terminus of this vector to that of vector $-\dot{A}\,\sigma^{-j\alpha}$ is found by means of dividers.

This length laid off along the horizontal scale will give the required value of voltage regulation.

Frank F. Fowle: The most important problem in the mechanical design of wire spans and structures is the choice of a safe assumption as to loads. In the recent joint report covering specifications for overhead crossings of electric light and power lines, prepared by a joint committee of the National Electric Light Association, American Institute of Electrical Engineers, American Electric Railway Association, Association of Railway Telegraph Superintendents, and American Railway Engineering and Maintenance of Way Association, the subject of loading has been considered with great care. Three classes of loading are there defined, as follows.

Digitized by Google

Class of loading	Loads		
	Vertical component	Horizontal component	Temperature
A	Dead	15 lb. per sq. ft.	
B	Dead plus ½ inch of ice.	8 lb. per sq. ft.	0 deg. fahr.
C	Dead plus ½ inch of ice.	11 lb. per sq. ft.	

Class B loading is the stated requirement in the specifications proper and the ordinary temperature range is given as −20 deg. to +120 deg. fahr. The weight of ice is given as 57 lb. per cu. ft. or 0.033 lb. per cu. in. The wind pressure requirement on poles or towers is 13 lb. per sq. ft. on the projected area of closed or solid structures and one and one-half (1½) times the projected area of latticed structures.

Mr. Thomas, who was a member of the joint committee, employs the class B loading in the example of span calculations given in his paper. Mr. Robertson also employs substantially the same loading. But Professor Pender takes exception to loading as heavy as this and says that the combination of ½ inch of ice and 60 miles per hr. wind velocity will seldom if ever exist simultaneously; he also says that sleet will seldom exist on a wire when the temperature is much below freezing.

Probably no one will dispute that sleet accumulates to thicknesses exceeding ½ inch, or that wind velocities (corrected) sometimes exceed 60 miles per hr., or again that temperatures fall lower than 20 deg. fahr. below zero. How much sleet or how much wind, or how low a temperature will really occur, are matters of probability, only to be determined with some approach to accuracy by studies of weather phenomena extending over long periods. It will be generally admitted that the extremes of wind, sleet and temperature do not occur simultaneously. What we wish to know is how far we must go in assuming simultaneous values in order to design spans and structures so as to be reasonably safe.

Fundamentally we ought to define what constitutes reasonable safety. Should we build expressly to prevent any failure whatever in the light of the most severe combination of loads ever known, or should we take a few chances and proceed to build so that the line will probably fail once in twenty years, or once in ten years—or how often? The question of probability, as applied to the occurrence of simultaneous loads of wind and sleet and the accompanying temperature, enters the problem at many points. Generally speaking, the probability of failure ought to be limited by the risks—that is, it ought to be inversely as the risk, to some extent. How far we *ought* to go in the elimination of risk is one thing; how far we *can* go is another. The engineer

Digitized by Google

who is radical on the side of safety is likely to be criticized by those who pay the bills, and the standard of engineering efficiency is perhaps judged mainly by construction costs, in some cases, when there are other important factors to consider.

But when the risks are considerable, and particularly when human life is involved, it seems proper to reject any assumption that failures at stated periods, even at very long intervals, are permissible. If this is sound, then we can limit the application of probability to the simultaneous values of wind, sleet and temperatures. The gathering of data on this question is a work of great magnitude, if the results are intended to be comprehensive and of substantial value. A preliminary effort in this direction was made by the writer, which consisted of an analysis of the records of the Weather Bureau at Chicago and was published in the *Electrical World* of October 27, 1910. The results of this study do not uphold Professor Pender's comments on class B loading, but rather indicate that heavier resultant loads would be justified—at least in certain localities.

In regard to the existence of sleet at temperatures lower than freezing, it is a fact, of course, that it will not *form* at lower temperatures, but nevertheless the temperature may fall after the sleet precipitation ceases—and fall considerably. At the same time the wind velocity may increase with the lower temperature, although it is generally stated, and apparently true, that extreme velocities do not occur at the lowest extremes of temperature.

In the matter of formulas expressing wind pressure as a function of velocity there is some disparity. The original form of Mr. Buck's expression, referred to by Professor Pender, is

$$P = 0.0025\ V^2$$

which expresses the pressure on the projected area of a bare stranded cable, in pounds per sq. ft. Mr. Buck's conclusions in relation to wind velocities are also well worth studying in the present connection.

For stranded cables the wind velocities corresponding to pressures of 8, 11 and 15 lb. per sq. ft. of projected cable, with Mr. Buck's constant and with a constant of 0.002 are as follows:

Values of P	Values of V	
	Constant = 0.0025	Constant = 0.002
8.0	56.6	63.3
11.0	66.3	74.2
15.0	77.5	86.6

It is worthy of note that the joint committee report permits an allowable safe stress in hard drawn copper of 50 per cent of the ultimate, or approximately at the elastic limit as determined by

Digitized by Google

the ordinary tests. For sustained loads copper has not as high an elastic limit as this percentage gives; the stretching which will take place, when copper is loaded up to its ordinary elastic limit, will produce considerable increase in the sag when the original span is tightly drawn. On that account it seems conservative to employ a larger factor of safety than two.

Another reason for increasing the factor of safety lies in the fact that the stresses due to swaying, and the resultant shocks, are not taken account of in the usual span calculations. Failures do not ordinarily occur under steady loads, but during the variable conditions which occur in a storm—when the wind is probably coming in gusts. At the same time any yielding of the poles, towers, or guys may throw additional stresses on the spans.

In the papers on high-tension operation at 100,000 volts, by Messrs. Jollyman, Lee and Higben, it is interesting to note that sleet has been experienced on such lines, although it has caused no extensive trouble. Mr. F. W. Peek, Jr., in his paper on "The Law of Corona and The Dielectric Strength of Air," gives some interesting information in relation to sleet. He says, "Sleet had already started to form on the conductors, and was still falling when the tests were started. Fig. 57, (of his paper), shows the loss curve. After the curves were taken the line was kept at 200 kilovolts for over an hour with no apparent diminution of sleet. This seems to show that sleet will form on high voltage transmission lines. The day after these tests were made was bright and clear and the conductors were still coated with sleet. A set of readings were taken, and it is interesting to note that the excess loss here is as great as when sleet was falling." These results seem to clear up any doubt as to the occurrence of sleet on high-tension lines, with copper conductors.

Mr. Buck, in his 1904 International Congress paper on "The Use of Aluminum as an Electrical Conductor," before alluded to, says:—"That aluminum wire gathers much less sleet than copper. This is due perhaps to the grease which is absorbed in the aluminum due to its porous qualities, in the process of wire drawing or from some other physical condition of its surface." Beyond this statement the writer has seen no definite or comparative data on the behavior of copper and aluminum in sleet storms.

During the winter of 1910-1911 the writer exposed several short spans of copper, iron and aluminum, in different sizes, to observe the effects of sleet precipitation. However, the opportunities for observation proved to be very limited and sleet occurred but once, and then as a trace only. This happened at night, when observations were necessarily hampered, but it was definitely learned that sleet commenced to accumulate on copper, iron and aluminum alike. It did not progress sufficiently, however, to reveal quantitative results for comparison.

Digitized by Google

R. C. Darrow: In the paper presented by Mr. Thomas a solution is given for the problem of finding the sag of transmission wires at different temperatures when the initial load conditions are given. This method will be found a short and convenient one and all the calculations can be made on a slide rule with sufficient accuracy for practical use. The method is based on the equations of the catenary and it may be interesting to compare the results obtained using this method with those obtained by some method in which the tension is given by the formula, $T = \frac{w\,l^2}{8\,d}$, and the length by the formula, $L = l + \frac{8}{3}\,\frac{d^2}{l}$

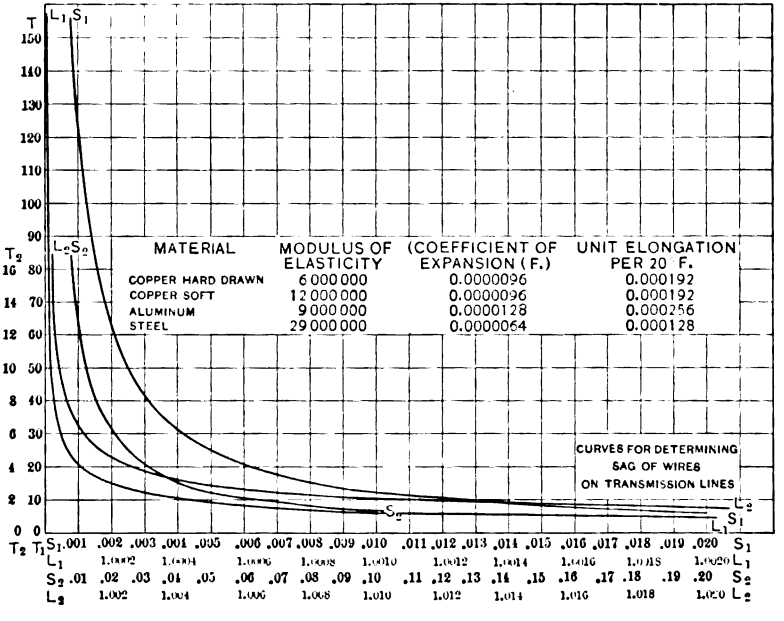

MATERIAL
MODULUS OF ELASTICITY
(COEFFICIENT OF EXPANSION (F.)
UNIT ELONGATION PER 20 F.
COPPER HARD DRAWN 6 000 000 0.0000096 0.000192
COPPER SOFT 12 000 000 0.0000096 0.000192
ALUMINUM 9 000 000 0.0000128 0.000256
STEEL 29 000 000 0.0000064 0.000128
CURVES FOR DETERMINING SAG OF WIRES ON TRANSMISSION LINES

PLATE I

where T equals the safe tension in the wire, w the weight per foot along the wire, l the span, and d the sag. Reference is made in Mr. Robertson's paper to an error introduced by considering the tension along the wire as constant and equal to the tension at the point of support. Following out this suggestion a curve has been determined giving a correction factor where greater accuracy is desired.

A set of curves which will be found to cover a wide range of problems and which check those of Mr. Thomas are shown on Plate I. The points (Table I) on this curve have been determined with a ten place logarithm table except those where the tension for the unit span is greater than one hundred. In

Digitized by Google

getting these points the formula, $T=\frac{1}{8}\ \frac{w\,l^2}{d}$, was used for the unit tension and, $l+\frac{8}{3}\ \frac{d^2}{l}$, for the unit length, experience showing that this would be accurate enough for practical prob-

TABLE I

Tension for unit span	Sag for unit span	Length for unit span
156.25	0.000800	1.000001707
138.88	0.000900	1.000002160
125.00	0.001000	1.000002667
113.63	0.001100	1.000003227
100.001250	0.001250	1.000004212
90.910466	0.001375	1.000005104
83.334833	0.001500	1.000006058
76.924702	0.001625	1.000007110
71.430321	0.001750	1.000008223
66.668542	0.001875	1.000009441
62.502000	0.002000	1.000010742
58.825654	0.002125	1.000012115
55.557806	0.002250	1.000013571
52.633954	0.002375	1.000015102
50.002500	0.002500	1.000016725
40.003125	0.003125	1.000026072
33.337083	0.003750	1.000037516
28.575804	0.004375	1.00005106
25.005000	0.005000	1.00006667
20.006250	0.006250	1.00010418
16.674167	0.007501	1.00015003
12.510001	0.010001	1.00026669
10.012503	0.012503	1.00041673
8.348337	0.015003	1.00059808
7.160364	0.017507	1.00081687
6.270011	0.020011	1.00106701
5.578071	0.022515	1.00135055
5.025021	0.025021	1.00166751
4.572982	0.027528	1.00201789
4.196703	0.030036	1.00240173
3.370904	0.037570	1.0037542
2.550167	0.050167	1.0066801
2.062833	0.062833	1.0104352
1.742231	0.075564	1.0150676
1.516968	0.088397	1.0205421
1.351340	0.101340	1.0268808
1.225522	0.114411	1.0340934
1.127626	0.127626	1.0421906
1.050092	0.141001	1.0511847
0.987888	0.154554	1.0610893
0.896549	0.182264	1.0836910

lems. This portion of the curve will seldom be used except for very short spans or sizes of wire such as number 12 or 14 N. B. S. copper, or a twisted pair of insulated number 17 B. & S. steel wire.

Comparison of this Method with One Using Equations Based on the Parabola. In the determination of a temperature—sag

Digitized by Google

curve the initial conditions at worst load are known together with the tension to be allowed in the conductor, the first step in the solution of the problem being to get the sag at the minimum temperature with the weight of the wire only. Curves given in Fig. 1 show the results for the original conditions obtained from the catenary curves and from the formula, $d = \frac{w\,l^2}{8\,d}$, using a tension of one thousand pounds and a weight per foot of one pound. These curves illustrate the variation in sags as the length of span increases and show, that the difference in sags determined by the two methods is quite marked when the per cent sag is increased, quite an error being introduced at the beginning of the problem by the use of the formula, $d = \frac{w\,l^2}{8\,T}$.

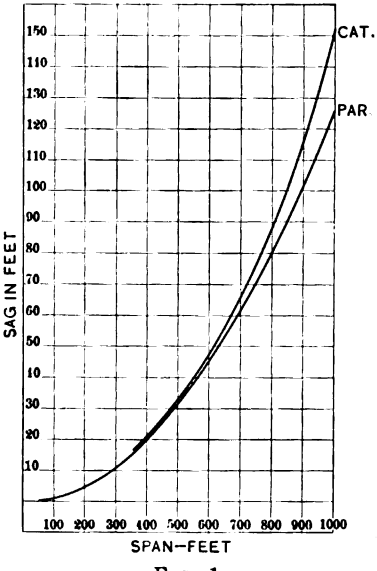


FIG. 1

Curves in Figs. 2, 3 and 4 show some comparisons between temperature-sag curves for various sizes of wire and different spans computed by two methods, those marked 1 being figured from a method based on the formulas, $T = \frac{w\,l^2}{8\,d}$ for tension and $L = l + \frac{8}{3}\,\frac{d^2}{l}$, for length, and those marked 2 being figured from the catenary curves. The variations in the two methods is brought out very distinctly by these figures which show that for a 100 ft. span and number 0000 B. and S. stranded copper wire the curves coincide, while for the larger spans the difference increases as the per cent sag is increased, those figured from the catenary curves giving larger results for the sag at the same temperature. In working out these problems, when the larger spans are used and greater per cent sags result, the points determined will not lie exactly on a smooth curve when the catenary curves shown on Plate I are used, but the discrepancy is so small that a smooth curve can be easily drawn through the points giving satisfactory results, and if more accurate results are desired the curves where the unit tension is small can be drawn on a larger scale. This refinement will not be necessary in practical work because of the inconsistency in the constants used for the

Digitized by Google

material and the inaccuracies arising from the assumptions made in the solution of the problem, one of these being that the tension along the conductor is constant.

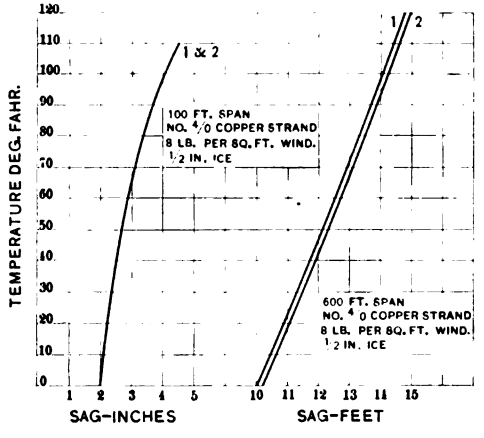


FIG. 2

Variation of the Tension along a Conductor. It may be of interest to develop a curve giving a correction factor for various values of tension at the point of support which may be used where

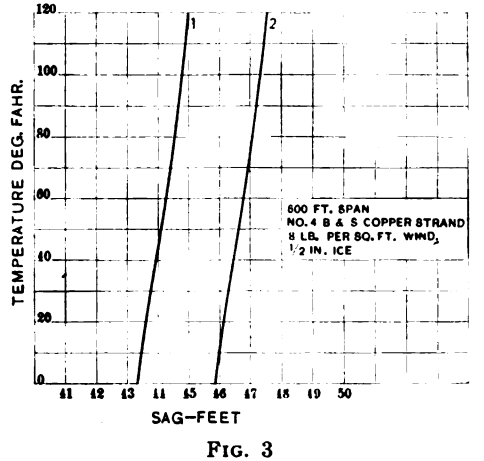


FIG. 3

greater refinement is desired. It can be shown that, if the average tension along the conductor is used, the contraction of the conductor when the stress is removed can be more accurately figured, giving a greater contraction than when the tension at

Digitized by Google

the center of the span is used and a smaller one than that given by using the tension at the point of support. This means that when the tension at the point of support is used the values of the sag at different temperatures will be too small and when the tension at the center of the span is used the values will be too large. The following method is developed so that the assumptions made may be clearly understood.

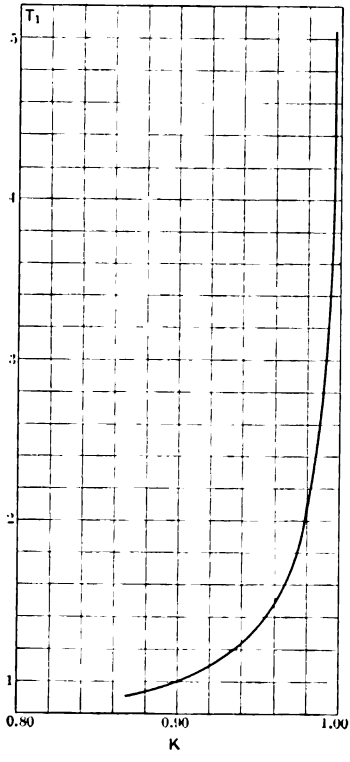


FIG. 4.—Curve for determining average tension along a transmission wire

T_1 = Tension at point of support for unit span

K = Average tension ÷ tension at point of support

Average tension = $T_1 \times K \times w \times l$

Contraction for unit span = $\frac{f K}{E}$

Let λ equal the contraction of any cord of length x, and let the tension along the cord vary as the length, such that $t = f(x)$. Then $d\lambda = \kappa f(x)\, dx$, and the total contraction, $\lambda = \kappa \int_0^x f(x)\, dx$. The term $\int_0^x f(x)\, dx$ will be the area between the cord as the x axis and the curve representing the tension, $t = f(x)$. This area can also be expressed by the length (x) times the average tension $(av.\ t)$, so that $\lambda = \kappa x\ (av.\ t)$. If $\kappa = \frac{1}{A E}$, where A equals the cross sectional area of the cord and E, the modulus of elasticity of the material, the equation becomes $\lambda = \frac{x\ (av.\ t)}{A E}$. If x is unity and the average fibre stress $(av.\ f)$ is $\frac{(av.\ t)}{A}$, the contraction for unit length (λ_1) becomes $\lambda_1 = \frac{av.\ f}{E}$, which subtracted from the unit length gives the unstressed unit length. The problem now becomes one of finding the average tension along a catenary when the tension at the point of support or center of the span is given. The equation for the catenary is, $y = c/2\ (e^{x/c} + e^{-x/c})$, and the length is, $s = c/2\ (e^{x/c} - e^{-x/c})$. The values of y along the curve represent the values of the tension and the average

Digitized by Google

value of y will represent the average tension. The average value of y along the length s is given by the equation,

$$av.\ y = \frac{\int_0^s y\,ds}{s}$$ Since $y = \frac{c}{2}(e^{x/c} + e^{-x/c})$ and $s = \frac{c}{2}(e^{x/c} - e^{-x/c})$

the equation becomes,

$$av.\ y = \frac{\int_0^x \frac{C}{4}(e^{+x/c} + e^{-x/c})^2\,dx}{\frac{C}{2}(e^{x/c} - e^{-x/c})} = C\int_0^x \frac{1}{C}\cosh^2\frac{X}{C}\,dx \Big/ \sinh\frac{X}{C}$$

$$= \frac{c}{2}\left(\cosh\frac{x}{c} + \frac{x}{c}\,\frac{1}{\sinh\frac{x}{c}}\right)$$

Since the length of a span equals $2x$, the average tension per unit span is given by the formula

$$av.\ y_1 = \frac{c}{4x}\left(\cosh\frac{x}{c} + \frac{x}{c}\,\frac{1}{\sinh\frac{x}{c}}\right)$$

$$= \frac{c}{4x}\left[\frac{(e^{x/c} + e^{-x/c})}{2} + \frac{x}{c}\,\frac{2}{(e^{x/c} - e^{-x/c})}\right]$$

If x/c has the same values as are used in determining the catenary curves, then for every value of the tension at the point of support, the equation will give a corresponding value of the average tension, or for every value of the tension at center of the unit span which equals the tension for unit span at the point of support minus the sag for unit span, we will have a value for the average tension. The value of the average tension divided by the tension at the point of support, will give a factor which may be plotted as absissæ with the corresponding tension for unit span as ordinates, Fig. 4. The values used in plotting this

Digitized by Google

curve are given in Table II. From this curve we can get the correction factor for any tension which may be used in determining the contraction from the formula $\lambda_1 = \alpha f/E$, where f is the fibre stress at the point of support. An examination of this curve shows that the factor is negligible except where the tension for unit span is low and these conditions will be found when the per cent sag is large. It must be remembered however that if this refinement is desired a new set of catenary curves must be drawn using average tension as ordinates in place of the tension values given in Table I. These ordinates can be found by multiplying the values of tension in this table by the proper factor. Also average tension should be used throughout the solution of the problem.

TABLE II

Tension for unit span			Sag for unit span	α Factor = column 3 / column 1
At point of support	At center of span	Average tension		
5.0250	5.0000	5.0083	0.02502	0.9967
4.5730	4.5455	4.5546	0.02753	0.9960
4.1967	4.1667	4.1767	0.03004	0.9952
3.3709	3.3333	3.3459	0.03757	0.9926
2.5502	2.5000	2.5168	0.05017	0.9865
2.0628	2.0000	2.0211	0.06283	0.9797
1.7422	1.6667	1.6921	0.07556	0.9712
1.5170	1.4286	1.4584	0.08840	0.9614
1.3513	1.2500	1.2843	0.10134	0.9504
1.2255	1.1111	1.1500	0.11441	0.9384
1.1276	1.0000	1.0436	0.12763	0.9255
1.0501	0.9091	0.9573	0.14100	0.9116
0.9879	0.8333	0.8866	0.15455	0.8975
0.8965	0.7143	0.7778	0.18226	0.8676

A value of one pound per foot of conductor was used in determining the above table.

P. H. Thomas: In answer to Mr. Lincoln's question, I will say that it is manifestly impossible to tell in a general statement how much a pole or pin will yield and it is impossible to take mathematical account of a lot of the varying conditions, and if we, by our papers, have enabled you to understand what the result of the known factors is, you can more easily make allowance for the others.

In regard to the effect of flexibility of supports, I think we will have to consider that two cases are likely to arise. There will be times on a long tangent, *i.e.*, along straight line, where the supports will be only slightly deflected, since the spans support one another. If we have a general increase in tension in the line the cross-arm cannot yield in either direction, because it is pulled in both directions. On the other hand, where we

Digitized by Google

have bends in the line, or where one conductor burns off, or some other unsymmetrical condition arises, we may have a great deflection in the tower, in which case the strains calculated by this formulæ will be wild of the fact.

I have spoken of broken conductors as a very important case. Assume that all the conductors are burned off on one side of the pole—not only do we have thereafter the strain that results from the tension on one side only, but we have a sudden shock as the wires due to the swing reach the lowest point. With suspension insulators the wire forms a sort of toggle joint and will produce a considerable strain as the maximum of the swing. In practice I have known no trouble on this score.

I wish to add one word to what Mr. Nicholson has said in regard to the proper spacing between wires, that proper spacing depends on other things than the voltage. This matter deserves a great deal of emphasis. I would add to the variables Mr. Nicholson named, the question as to whether the type of insulator is pin or suspension, for the suspension insulator, having a free swinging motion sidewise, requires a much wider spacing of conductors than the pin type of insulator.

Mr. Robertson's statements about the "stretch" curves on my diagram are perfectly just. They are true, I think, within all ordinary ranges; if you go beyond the elastic limit they are not true, but it is true that you can get the exact result by plotting, instead of the straight line, the actual stretch curve, whatever it may be. If you know you are going beyond the elastic limit, and know what the curve of material is, plot it on the diagram.

I consider the method Mr. Robertson says has been suggested to him, that of stretching soft wire tighter than the ultimate condition will allow, and letting it stretch when the strain exceeds the elastic limit, is a dangerous proceeding. If the wire is perfect, and you know it will stretch uniformly, there is much to be said in favor of the idea. If, however, there are any joints in the wire, or there is any danger of its being kinked, or nicked, the stretching will come at some one point rather than uniformly throughout the wire, and you do not know what condition will result.

W. L. R. Robertson: In Mr. Fowle's discussion, he has very appropriately considered the assumption of proper loading and the proper safety factor. In the 1911 overhead line report of the Pennsylvania Electric Association, the writer makes a few suggestions that are closely in accord with Mr. Fowle's ideas. It seems that in overhead line construction the tendency is to base calculations on very narrow margins of safety. In other engineering problems such as building construction, etc., we assume loads on our structures up to the extreme limits, and in addition to this we employ safety factors up to 5 and larger. We are, indeed, handicapped in our calculations by not having definite conclusives in these matters.

Digitized by Google

In regard to wind pressures on wires up to the present time Mr. Buck's expression:

$$P = 0.0025\ V^2$$

is generally conceded to be correct, but in conjunction with the study of Mr. Buck's conclusions, attention should also be given to an article in the *Journal of Electric Power and Gas* of July 29, 1911 by Messrs. Piatt, Lane and Kistler, wherein they claim very much higher wind pressures than given by the above expression especially for the smaller wires.

In answer to Mr. Thomas, when he criticizes the stretching of annealed copper as a dangerous proceeding, the writer has not recommended the stretching of any wire beyond the ultimate conditions. If stretching is carried on too far, it most assuredly is dangerous, but if soft copper is to be used at all in overhead lines and to be erected with reasonably small sag values then a certain amount of stretching cannot be avoided. If 17,000 lb. per sq. in. or ½ the ultimate strength is the proper allowable stress as recommended in the overhead report of the National Electric Lighting Association, June, 1911, then the stretching of soft copper is considerable. In fact the elastic limit of annealed copper is very low and indeterminate, and it would be impracticable to use annealed copper without stretching. Further on this basis satisfactory calculations cannot be made for annealed copper unless data on permanent set, increase in tensile strength due to stretching, etc., is available.

P. H. Thomas: Attention should be called to the ingenious method of Mr. R. S. Brown, found in the discussion of these papers, in which he has simplified line calculations. It is well known that in any transmission wire not containing loops there is an inherent relation between inductance and capacity, so that one property bears a definite numerical relation to the other property, this relation being expressed by the equation $L\,c = \frac{1}{V^2}$ where V is a constant approximately equal to the velocity of light. The relationship is a matter of actual fact somewhat disturbed by conditions within the conductor, but presumably not sufficiently to interfere with its practical accuracy for general work. While this relation has been well known, as far as I am aware, it has not previously been directly applied to the simplification of equations containing both inductance and capacity as apparently independent variables.

Considering Mr. Fowle's discussion of the choice of maximum conditions to be met by any particular structure, I would like to call attention to one saving fact, namely: that, should a strain appear on the wire greater than the elastic limit, the result will not ordinarily be the rupture of the wire but merely a certain stretch which will greatly relieve the tension in the span. This

Digitized by Google

condition serves practically to greatly extend the extreme conditions under which an actual rupture and falling of a line conductor would be expected. This favorable situation exists, of course, only with regard to the wires or cables strung along the poles and does not extend to the line poles, except as against such strains as are produced by the toggle effect of the suspending wire. In the case of a stretched wire it will of course sometimes be necessary to take up slack afterwards.

I should like to call attention to Mr. Darrow's communication to my paper as representing a very careful study of the method and its relation to the present ordinary methods. Mr. Darrow has given the values upon which the curves of chart No. 2 of my paper are drawn, but has extended the computations to more significant figures in such a way as to permit the application of the curves to much tighter spans, such as are frequently used in telephone and relatively low voltage distribution work.

Harold Pender and H. F. Thomson: The object in presenting the detailed derivation of the formulas in our paper was to put in a readily accessible place a complete discussion of the limitations of the approximate formulas used in practice. We should have been no more surprised than Mr. Lincoln had we found that for short spans the assumption of a parabola introduces a considerable error and that in the case of short transmission lines the simple method of calculation ordinarily used gives erroneous results. In view of the fact that long spans and long lines are becoming more and more frequent it is important that the limitations be recognized. We wish to point out again that the complete rules for the use of the charts are given on the charts and that it is therefore unnecessary in using them to refer to the detailed deductions in the text.

The method of solving the wire span given by Mr. Thomas is exceedingly simple in theory, but requires considerable slide rule calculation. Our chart gives the same results but only a single slide rule computation, a simple multiplication, is necessary. To show the graphical portion of our solution we have reproduced as Fig. 6 the part of Chart No. 2 necessary for the solution of the example of the aluminum wire span given at the foot of the chart. The location of the points A, B and C has been explained previously. It will be noticed that only two of the system of curved lines given on the chart are necessary for any single solution. It should be observed also that for a given span the tensions and deflections for any series of stringing temperatures may be found by locating other points like C by means of lines parallel to $B\ C$ and passing through the corresponding temperature points on $A\ B$. A number of such lines for the above example are indicated in Fig. 6. The advantage of this chart when one has to make a number of calculations for different lengths of span or for various temperatures with a given span is evident.

It is worth noting that the relation $L\ c = \frac{1}{V^2}$ used by Mr.

Digitized by Google

Brown applies only to overhead transmission lines where the capacity is not influenced by the presence of other conductors or the earth. The relation does not hold for a lead sheathed cable, nor does it hold for a loaded telephone line. This also applies to the capacities given on our Chart No. 3.

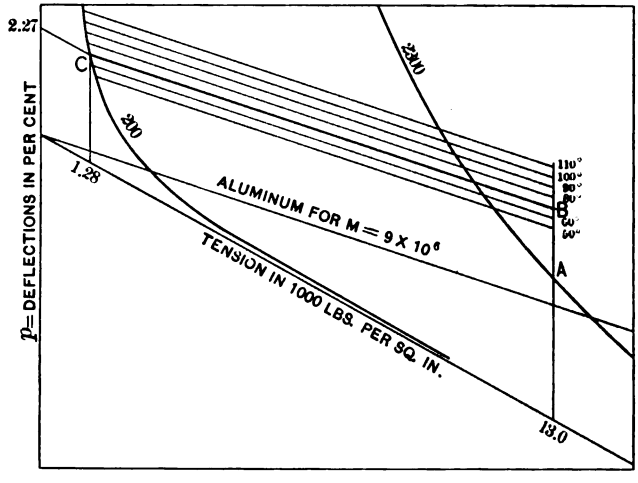


FIG. 6.

Location of points *A*, *B*, and *C* for example of aluminum wire given on Chart No 2 For tensions and deflections at stringing temperatures other than 70 deg. fahr., draw lines parallel to *B C* through points on *A B* corresponding to the respective temperature corrections, as 50 deg., 60 deg., etc.

In the paper the report of the Joint Committee on Overhead Line Construction is mis-quoted. Their recommendation for the maximum load is the simultaneous existence of 0.5-in. of ice, a wind pressure of 8 lb. per sq. ft. and a temperature of 0 deg. fahr., not −20 deg. fahr. as stated in the text. Our attention was called to this error by Mr. R. D. Coombs.

The error pointed out by Mr. Robertson in Fig. 3 in his paper, when the points of support are not on the same level, does not enter into our Formula No. 31. The phenomenon referred to is taken account of by the second term in the parenthesis.

Digitized by Google

DISCUSSION ON "ELECTRIC LINE OSCILLATIONS." CHICAGO, JUNE 29, 1911. (SEE PROCEEDINGS FOR JULY, 1911.)

(Subject to final revision for the Transactions)

C. P. Steinmetz: Mr. Faccioli's paper gives an oscillographic investigation of the transients, that is the oscillations, traveling waves, etc., produced by switching operations in transmission systems at the utmost limits of voltage and distance reached today: a 100,000-volt system, comprising a three-phase circuit of over one hundred and fifty miles, and in some of these oscillographs, records are presented in which two of these lines have been connected in series, so giving a circuit of over 300 miles operating at 100,000 volts. The taking of these oscillograms naturally involved considerable difficulties, quite a number of problems, which are discussed by Mr. Lewis. Specially favorable conditions for the investigation of the phenomena existed in this circuit, as oscillograms could be taken at the generator end, at the receiving end and in the middle of the circuit, and thereby it was possible to investigate the propagation and the attenuation of line disturbances, created at one point of the line, and the effect produced by them at other points, at the middle and ends of the line and at the transition points between line and other apparatus. Tests were made on opening and closing the circuit at the generating end of the high potential lines, by high potential switching and by low potential switching, with the line open at the other end, and with the line connected to step-down transformers. Tests are also given of the phenomena occurring when 150 miles of line is switched to another 150 mile line, or switched off, at 100,000 volts.

An interesting and important conclusion from these tests is that the oscillations and disturbances of such a system are not those of a line or circuit of uniformly distributed capacity and inductance, are not the phenomena usually described in the textbooks, but that in the oscillation the transformers and the generating system participate, and the oscillation thus is a compound oscillation of the system, comprising different sections of different characteristics and constants: transmission line, step-up transformer, generator. Two conditions exist, one, where the circuit consists of the transmission line, the leakage reactance of the step-up transformer and the generating system, with transition points between these circuits. The other condition results by disconnecting the generating system from the line, and gives a circuit comprising the transmission line and the mutual inductive reactance of the transformer, which is very many times greater than the leakage reactance, and is an ironclad reactance, while the leakage reactance is essentially an air reactance. The latter case results in a frequency of oscillation of the compound circuit which is very low, below machine frequency, reaching as low as from 20 to 30 cycles. As seen in Figs. 8, 9, 13, 20, etc., voltage and current waves are distorted greatly by the periodic variation of the ironclad inductance, and successive half waves increase in length, due to the increase of in-

Digitized by Google

ductance with the decrease of voltage and thus of magnetic density. When the generating system is implicated and surges with the line, the transformer inductance is much lower, as it is the leakage inductance, and the frequency of oscillation of the compound circuit is higher, is between the second and third harmonics, approximating 120 cycles. A number of interesting phenomena result by a superposition of this frequency of oscillation on the fundamental generator frequency, since the oscillation frequency is approximately twice the generator frequency. This means in the resulting current alternate half waves are subtracted from each other and added, so that there are successive periods where the current is nearly extinguished by superposition of two opposing currents of the two different frequencies, and periods where it is exaggerated. Such a current passing through a high potential switch gives the effect that the arc is extinguished at the low current values and rekindles again at the high current values. This gives not a single transient oscillation, but a series of successive transients, as shown in the oscillographic records Figs. 1, 2, 10, etc. Fig. 2 especially gives a very long extinction of current. We must consider that in switching at these high voltages the contact is not made and broken as metallic contact, but before the switch terminals meet, the spark jumps ahead and closes the circuit by an arc. When the switch contacts separate in opening the circuit, the arc follows for quite a number of cycles.

It is obvious that the arcs of the different phases do not necessarily extinguish at the same moment, nor start at the same moment, and that, therefore, even if the switch mechanism of all phases is absolutely simultaneous in its action, the actual closing and opening of the circuit of the different phases is not simultaneous, but some of these open or close ahead of the others. This gives a momentary unbalancing of the circuits, and leads to some interesting phenomena as shown in the records, Figs. 7, 14 and 15 etc. Specially noteworthy is the frequent appearance of high frequency waves, as shown in most of the oscillograms, Figs. 1, 2, 3, 10, 12, 16, 17, 18, 19, 20, 21, etc., which indicates that high frequency is an ever present phenomenon in high voltage transmission lines. The observations made with spark gaps across small inductances give further evidence of extremely high frequencies. Especially interesting is the appearance of a high frequency oscillation in a transformer when disconnecting it from the line, as in Figs. 16, 17, etc., as this shows the danger to which the transformer is exposed. Fig. 20 is interesting by the superposition of a high frequency oscillation of rapid decay, on the low frequency oscillation of the compound circuit consisting of 150 miles of line with step-down transformer, produced by disconnecting this circuit from another 150 miles of line. Here the origin of the high frequency seems to be the readjustment of the stored energy between the sections of the compound circuit, which precedes its oscillation as a whole.

Digitized by Google

Especially important is the absence of high frequency in the oscillograms taken at a considerable distance from the starting point of the disturbance, as the switch. This illustrates that high frequency does not travel very far, but is local, and that the more, the higher the frequency: the extremely high frequencies observed by spark gap across a small reactance, had vanished already at a short distance from their origin.

The starting transient of a transformer is shown in Fig. 15, which illustrates the excessive starting current, lasting for many cycles, and its unsymmetrical shape, resulting from even harmonics.

It is obvious that I cannot discuss in detail the oscillograms, but they have to be carefully studied from the records. However, the conclusions from these investigations are essentially that switching in a high potential circuit of considerable capacity is a dangerous operation, even with the oil circuit breaker, and therefore it should be avoided as far as possible. It is dangerous, however, only if the switching occurs at or near a transition point between circuit sections of different constants, near a transformer, but no danger results where switching is done in the middle, or inside of a homogeneous circuit, as from one transmission line on to another transmission line with no transition point near it. Therefore, where a change in the circuit constants by a transition point is near, as a transformer, you should arrange the switching on the low tension side, as this is safe, but where there is no transformer nearby, you have to switch in the high tension side, but there all the circuits which are involved are line circuits of the same or similar constants, and there switching is relatively harmless. Furthermore, these records show that whatever takes place, any change of the circuit conditions results in the appearance of high frequency, and high frequency is in those high voltage systems an ever present phenomenon, as much as the waves of the ocean are ever present. High frequency impulses, as oscillations of current, and corresponding oscillations of voltage, are of moderate amplitude, usually not high enough to raise the voltage of the system sufficiently to discharge over the lightning protective apparatus, and lightning arresters therefore usually can not take care of these high frequency oscillations. Their danger consists in the possibility of locally piling up the voltage, in inductive parts of the circuit, as in the end turns of the transformers, generators, etc., etc. The danger of these high frequency surges thus results not from an increase of the voltage of the system, but from the local excessive potential differences which they may create in apparatus.

Max H. Collbohm: The main points brought out in Mr. Faccioli's paper are, in the speakers' opinion, the following two:

1. The fact that the higher harmonics in the generator wave at no load practically disappear with a certain increase in current.

2. The appearance of high frequency oscillations during switching operations in long distance transmission systems.

Digitized by Google

I have made the same observations in a 66,000 volt 25-cycle 63 mile transmission system where the generator wave contained at no load the 17th harmonic of about five per cent amplitude. The influence of this 17th harmonic could, however, not be detected by any appreciable increase in the charging current over that due to the fundamental frequency.

This seems to indicate that in a high voltage transmission system the requirements for a smooth generator voltage wave without harmonics, which heretofore have been strongly advocated, lose a great deal of their importance.

Regarding the second point, *viz.*, the high frequency oscillations of moderate amplitude and the consequent building up of high voltages when meeting inductive reactance, it must be said that our present American types of arresters including the electrolytic arrester, do not afford any protection whatever under such conditions.

As pointed out in my discussion on Dr. Steinmetz's paper on "Central Station Development," there has however recently been developed in Europe an arrester to meet just that particular condition. It consists of one or more banks of dry condenser elements shunted by a choke coil of very high reactance. The condensers acting on high frequency while the choke coil takes care of static accumulations. This type of arrester has been installed in various prominent European transmission plants with great success.

In the same discussion there has also been mentioned a scheme devised by the speaker for protecting against high frequency disturbances, namely, the use of solid iron wire of high permeability for station wiring, extending from the high tension transformer taps to the point where the arrester taps on to the transmission line. The choke coils being also wound with soft Swedish iron.

The protection afforded by this scheme is obtained by the very high resistance of the iron wire under high frequency, due to the skin effect.

The same discussion also mentions a scheme to protect the high tension series transformer from damage due to the high frequency, which consists in the use of a small electrolytic cell shunted across the high tension terminals of the series transformer. The before mentioned schemes have been tried out with entire success in a prominent hydroelectric plant which has passed through a great number of very severe lightning storms which caused the arresters to act very frequently without the least damage to the station apparatus.

D. B. Rushmore: The real motive of Mr. Faccioli's paper is that high tension transmission systems have been causing disturbances, and as the voltages have been increased there have been certain breakdowns in insulations and in apparatus, which were not understood, and a great many theoretical explanations have been offered for them, but so far as I know this is about the

Digitized by Google

first actual investigation of this particular class of phenomena on an actual transmission line of high voltage to find out what really existed there. Our transformers may break down, and it is very difficult to tell why they do break down. As both manufacturers and operators are desirous of avoiding failures, it is necessary to actually investigate the phenomena taking place on transmission lines, so as to have facts at hand, instead of more or less empirical hypothesis. We have certain elements of mass, velocity, inertia, elasticity in mechanical or electrical systems, and it helps very much to have us understand what is taking place in electrical systems, if we form some conception of the mechanical analyses. Interrupting a high tension circuit often makes me think of a fact in our daily experience, in earlier times, in getting the running light losses on synchronous motors, by throwing the belt, which used to be an exceedingly interesting thing with large motors—we used to throw it across the shop, anywhere in the neighborhood to get it out of the way, and you have just about the same element when the transmission of energy is interrupted very suddenly, we have about the same class of phenomena, with very different appearance. After having investigated and discovered what the real facts are in high tension switching, we can understand the matter more clearly; and I want to offer here a word of sincere appreciation for this investigation and for the elucidation which this matter had from Dr. Steinmetz both before and at the meeting, in clearing up a great many vague ideas which we had of what was taking place on transmission systems.

As a matter of fact, on high tension transmission systems the insulation is getting to be so strong, that if every thing is in proper shape, the number of disturbances is going to be very much smaller, because while these oscillations may exist the voltages induced by them are below the factor of safety of the insulating material on the line and on the apparatus, but, as Dr. Steinmetz very clearly brought out, the line is not the only thing to be considered, because when we have an oscillation of electricity, as it is playing back and forth into the capacity of the line, or through some leak of the line into the capacity of the ground, the place where the harm is done is where the voltage piles up, and that is always across the reactances.

Now, in the future design and operation of transmission systems we are going to find out through that wonderful instrument the oscillograph—and it is rather interesting to note in these scientific investigations the important part the oscillograph has played—more and more nearly exactly what is taking place, and we shall have an increased ability to interpret the results, something that is not always done without a considerable expenditure of time and money. But as a general result, somewhat repeating what has been said, the result of this very important and interesting investigation is a reassurance concerning our ability to deliver uninterrupted power to our future high tension transmission systems.

Digitized by Google

C. P. Steinmetz: I would like to make a few remarks regarding the spark gap test that showed a voltage of some 20,000. From the characteristics of the line, you get the relation between voltage and current of the transient: $\sqrt{\frac{L}{C}}$, and from the starting voltage of the transient, we get the transient current. This, with the inductance of the reactive coil, gives the frequency required to produce the observed spark voltage of this traveling wave. This calculation gives an approximate frequency of 2,000,000 cycles. We thus find that there are frequencies of oscillation moving around the system, varying from 20 cycles, which is the oscillation of the transformer, up to the magnitude of 2,000,000 cycles.

Percy H. Thomas: As Mr. Rushmore has said, this work of Faccioli's is one of the first efforts that has been made on a full sized plant to determine just what happens by actual measurement in generators and raising transformers at the time of switching. It would be well to consider in connection with this paper a paper presented at the Asheville Convention of the Institute in 1905, which was a somewhat similar study of the static effect produced by switching. These results, you will remember, were obtained in 1902 on some plants in the middle western part of this country. The tests were limited strictly to the experimental study of static phenomena, which as Dr. Steinmetz said is not the subject of the present paper—these two papers thus become complementary.

For fear it should be considered a misprint, I will call your attention to a point in the table under 4-*a* opposite 14 in. the last column, you will note that $1\frac{1}{4}$ in. spark-gap was jumped at the receiving end across a small choke coil in series with the line, representing a momentary voltage of 24,000 volts. This is a purely static phenomena of course, this measurement of voltage across the choke coils having been an incidental test in connection with the main experiments. The point about that extra high voltage, this being higher than in any other test, is brought out in the other paper of which I speak, namely, that the most serious results of a static nature from switching come when you connect a piece of apparatus of a different potential to a line which has stored in electrostatic capacity a sufficient quantity of energy, so that it can *instantly* charge the idle apparatus with which you are connecting it. This particular case was a transmission line, on the end of which was a transformer, the transmission line having a large capacity of energy stored, ready for immediate delivery, if you will accept that expression, to charge up the transformer initially or nearly. The result was that a choke coil connected to the lead of the transformer, received a very excessive strain.

Digitized by Google

DISCUSSION ON "TRANSMISSION APPLIED TO IRRIGATION", AND "TRANSMISSION SYSTEMS FROM THE OPERATING STANDPOINT." LOS ANGELES, CAL., APRIL 25, 1911. (SEE PROCEEDINGS FOR APRIL, 1911.)

(Subject to final revision for the Transactions.)

A. H. Babcock: Mr. Woods' paper is practical because it is based on real experience. For some years it has been my opinion that if more such experiences were put on record much good would result.

The author states that for distances up to 150 miles it is immaterial whether the capacity is taken as being all at the center, part at the ends, or uniformly distributed. Perhaps he will be willing to give his opinion where the line must be drawn, *i.e.*, what is the limiting distance where one's assumptions should change.

It is also stated that the tower should be designed for the unbalanced strains produced by the failure of any conductor. Is it not usual that when one line fails it takes another with it? It seems to me that it is necessary to go a little further and to provide for simultaneous failure of at least two conductors. Of course the financial conditions of the problem must determine in the end how far such insurance can go.

The author's remarks on switching must strike forcibly those who have been obliged to remodel switching and bus bar structures that have been found inadequate.

C. L. Cory: An interesting point brought out in a paper presented in San Francisco last May by Mr. Hays on the irrigation system developed in the San Joaquin Valley for the Mt. Whitney Power Co. was that in that plant certain economies resulted from not investing too much money in the beginning.

Wooden flumes were found in that particular installation to be quite satisfactory, and wooden pole lines gave good results. In the beginning the load was not heavy; and as the load increased, a reserve steam plant was installed down in the valley; and as an ultimate result the plant was a success. In other words, the duration of time necessary to get a load for this irrigation plant was such that it was not advisable to build a plant at first for all time.

The two plants described by Mr. Ensign and Mr. Gaylord, while for an entirely different class of service indicate that there are some circumstances where the character of work may even in our irrigation problems be permanent. I believe that the authors will agree with me that perhaps there are instances where this excellent construction would hardly be justified in the very beginning, as unquestionably was the case in the early days of the Mt. Whitney Power Company.

But when we see plants designed, laid out, and completely developed in every detail, such as the plant in Idaho and the one on the Salt River, we are impressed with the fact that irrigation and the use of electricity in pumping for irrigation, has come to about the same standard as the transmission plants for

Digitized by Google

metropolitan use for transportation and other purposes. I have had the pleasure of seeing the plant at Salt River, not all completed as described in the paper today, but there are a number of features about that plant that I recall. The tower line from Roosevelt into Mesa and Phoenix is a pleasure to see. There is a separate telephone line put up in a permanent manner—not upon wooden poles but upon inexpensive pipes or straight iron poles, and the entire construction is excellent.

There is one thing in making even a preliminary investigation of the installation of electrical plants for irrigation, which has to be constantly borne in mind. Mr. Ensign, as I remember it, said this morning that the capital charge against the land which would be irrigated from the Idaho plant was about $40 per acre.

Now, ordinarily when we build a large steam generating plant, or a transmission system which is used for transportation purposes, light, heat and domestic use, we do not necessarily have to consider the source of the money to pay for the income on the investment which ultimately takes care of all such charges, as depreciation and operating expenses. When we start to irrigate 200,000 acres of land, such as the Salt River project, including the storage reservoir, Roosevelt Dam, and canal system, and you see this land, as you might have seen it 10 or 15 years ago, you are impressed with the fact that the $40 per acre must come out of the productiveness of the land itself. In other words, it cannot come as an immediate result. The $40 per acre may possibly come in a few years, or it may require a number of years. In general, whether we have a gravity system of irrigation, or a large electrical installation, with the pumping plants and so on, the capital invested, the maintenance charges, cost of operation, and so on, will not be returned as rapidly as in many other installations of large plants. The investment is reasonably safe if the supply of water to be pumped is permanent and of the proper character, but there cannot be that immediate return, nor, I suppose, is it possible as quickly to load up the plant.

There is one point about which I would like to ask in regard to the first paper, and that is the period of the year or the annual load factor, if we might put it that way when electrical power would be used or needed for irrigation. To put it more definitely, I have in mind one location in New Mexico where it would not be necessary to pump water earlier than the latter part of February or the first of March. The summer rains come along in August, and it is only between March 1st and August 1st when the crops are starting that pumping is required. It is an important problem, under some circumstances, as to what we are going to do in irrigation projects with the power that may be generated at another period, or what are we going to do with our transmission plants of the character of the Idaho plant, if it is true that our irrigation is only needed five months out of twelve?

Digitized by Google

E. F. Scattergood: I wish to commend Mr. Ensign for having presented some cost figures in connection with the projects which he has taken time to describe. I do believe, further, that the time which we spend, as engineers, in writing descriptions of projects, and in reading descriptions written by others, is doubly valuable when accompanied by a statement of the features of construction and operation that have proved good and also of those that have proved unsatisfactory. We do not always hear about the bad ones, as we should and we should always be given the costs.

I remember very well my early experience with the Los Angeles Aqueduct work in planning for power for construction. I looked here and there and probably overlooked, but found very little of any benefit to an engineer wanting to know how much power is required, in a general way in construction work of that character; in what way to apply it and something as to costs. It seems that power is one of a number of such items that are usually allowed for by a sufficient percentage in estimates and paid but little attention while constructing such works resulting in an unnecessarily large total cost. After the first two years of aqueduct work I made careful summaries of the results as to the amounts of power required; the best methods of applying it; its bearing as to economical tunnel and conduit construction; the actual costs of the power system and the power delivered and comparisons with what the costs would have been if supplied by other methods. This was done for my personal use but when completed it was given to the Institute as published last August with the hope that it may be of benefit to others.

More such frank statements as those by Mr. Ensign would mean better team work and much greater accomplishment with an incidental betterment in the standing of the profession and every man in it. I do not see any disadvantage in it. I do believe that sometimes it might do perhaps some little harm, but I do believe there has been more harm done through ignorance of costs on the part of the public, than there ever would have been done through a proper knowledge of costs. There has unquestionably been great harm done, at times, through ignorance as to costs and in far more instances even greater injustice and wrong committed by taking advantage of such ignorance. I would like to know from Mr. Ensign whether or not the department would be free to develop power not needed for pumping purposes, and sell it, in order to make the results of the irrigation project more favorable to the farmer?

Paul M. Downing: In looking over Mr. Wood's paper, I find that his experience along different lines is very much the same as my own. He states that he does not consider any type of automatic regulator as being satisfactory for controlling the voltage at the generating end of a long transmission line.

This is particularly true of a large net work supplied from a number of different sources. On a system of this kind there are

Digitized by Google

a great many conditions coming up which affect the power house regulation. The character of the load may vary through a wide range during the 24 hours. The voltage regulation of one generating station will be dependent not only on the load carried from that station, but on the load carried from every other generating station, etc.

The conditions are entirely different from those obtaining where you have a single generating station and no inter-connected net work of lines.

I cannot agree with him when he states that the first cost of a synchronous condenser is a strong argument against its use. On the contrary, I think that very often it is an economical way of increasing the amount of power which can be delivered over a line.

On any long, high voltage line you almost invariably have a low power factor due to the induction motor load. This, together with the inductive drop in the line, gives poor line regulation. The use of a synchronous condenser enables you to raise the power factor to more nearly unity, but gives a most satisfactory means of regulating the line voltage.

The lightning arrester trouble to which he refers is something I think we have all had more or less experience with. Fortunately here in California there is little use for lightning arresters except in the higher altitudes.

Our greatest trouble, particularly in the Bay Districts, is from poles burning due to leakage over the insulators. Where you have one case of lightning trouble you will have a dozen cases of trouble from poles burning. This condition is generally the worst about the time of the first rains when the insulators are covered with the summer's accumulation of dust before they are washed by the winter's rains, and sometimes even two and three times during the summer and fall, to prevent this burning. After the first heavy rain little if any trouble of this kind is had.

J. A. Lighthipe: One of the points that was brought out by Mr. Wood's paper very strongly is that those who build a power system have no idea of what it will grow to be. The northern part of this State is practically under one system.

In Santa Anna we started with 33,000 volts, and 3000 kilowatts, and we were wondering what we would do with all that power. The whole line is now running in the opposite direction. The section surrounding Redlands is using about 10,000 kilowatts, and it is an open question whether we won't pump a great deal more to that end of the valley before many years.

The whole question of laying out stations and lines is a matter of prophesy. We don't know what we are going to run into in a few years. Fifteen thousand volts seemed to be almost the limit up to a few years ago. The first step to 30,000 simply staggered all the manufacturing companies. I can remember Dr. Bell publishing papers in which he stated that 40,000 was the limit that we could go; and we could not possibly

Digitized by Google

run beyond that. Now 60,000 is a common proposition. It is an open question whether we won't creep up to 100,000 or a 150,000, and we will have to if we increase our distances and areas of distribution.

Ralph Bennett: Mr. Lighthipe has mentioned the increase in voltage in recent years. We have now been operating in the Bay district for some time with 100,000 volts, and we have no more trouble with it than Mr. Downing had with 60,000 volts. In fact most of our trouble has been acquired from the 60,000 volt circuits which we feed.

A question has been raised as to the proper strength of towers. It is true there are times when several wires fail, but it is also true that there are usually additional circuits on the tower wires which will not fail and which will aid it in standing. Our suspension insulators are good for 15,000 lb.

After a flash-over, due to fog on the insulator, or lightning trouble, we can at once resume service. It is not like the old condition with wooden poles and wooden arms, where when we burned the pole head off we had to send a crew out to fix it up.

C. W. Koiner: Messrs. Ensign and Gaylord's paper on Transmission should be of very great interest to all companies operating in the West.

Power for irrigation is now furnished on a great many transmission systems throughout the southwest. It should be profitable for the reason that this load can be taken on the off-peak. The paper is full of valuable detail cost, and it is apparent that a fair price can be received for power.

The construction cost when compared with similar cost of work elsewhere, is very low. This same thing applies to Table 2.

The capital cost allowable per acre for irrigation depends entirely upon what the returns are per acre. It should be remembered that to rehabilitate the old eastern farms and plantations in the South, we are called upon to put back in the soil from $15 to $30 per acre, and sometimes $40. If it costs $40 per acre to irrigate virgin soil in the west, this should not be high, when we compare it with our old eastern farms, and they are beginning to return increased profit on the cost of rehabilitating. It would be interesting to know to what extent power is used for heating from the Idaho plant in the winter.

L. J. Corbett: Mr. Cory raised the question of the length of time that the power was used for irrigation. Up where we are we have even a shorter season than he seems to think is profitable. Some of the contracts I have been instrumental in getting on propositions of that kind from power companies have been as low as three months. One hundred days is the usual irrigation season, and sometimes, for safety, we stretch it from the 15th of May to the 15th of September, making it four months.

A question, which was hardly an electrical one, but more of an irrigation question, that was interesting, was the idea of using the surface waters and preventing them from rising beyond a

Digitized by Google

certain level and reducing them by taking them off and using them elsewhere for irrigation. That was a difficulty in the early days, in the Yakima region, and a great many people used it as an argument against irrigation, saying that it spoiled the land, making it sour, and that after a few years the land was ruined; but with the methods that are being developed now and the studies being made, such damage will be prevented.

Around Spokane there is a very interesting condition. The Spokane Valley is all underlaid with gravel. There are deep gravel beds ranging from 50 to 150 and even 250 feet deep. We have not gone to the bottom of them, but there is a water sheet there that certainly contains more water than the Spokane River, that travels right down through the valley. There is coarse gravel at most places at the water level, but there is such a flow going through that if you drop chips or sawdust on one side of a well, it is but a little time until it goes to the other side in the direction in which the river is flowing. To show what a heavy flow there is I would say that from wells eight feet in diameter, large centrifugal and turbine pumps are pumping as much as 5000 gal. a min. without visibly lowering them. When the pump is first started the water level falls from a foot to a foot and a half, where it remains constant. It pours right in from the sides. It is just like pumping out of a lake. The land the water is applied to is a black gravel soil and there is no danger at all of souring that land. The water is never left on the surface except in some cases in the winter when the ground is frozen and the melting of the snow leaves pools. It is well drained naturally. They are putting in wells there and buying power from the power companies.

In the discussion it was brought up by one of the members that irrigation came on the off-peak period. There are two companies furnishing power there, and one company, which has had a railroad and lighting load offered a special contract at reduced rates, if the irrigators would keep off their peak, which was from five in the evening until 11 o'clock at night; but in this particular place in the valley, tracts were being sold to parties living in and around Spokane, and many of the purchasers were working in Spokane and would come out there in the evening to take care of their suburban homes. Also the evening was considered the best time to irrigate and in this case that contract was refused and a higher rate paid in order to be at liberty to irrigate at any time.

R. W. Sorenson: I believe a good many of the companies have adopted the practice in calculating transmission lines for high tension of limiting the capacity in one line to about 20,000 kilowatts. In the paper given by Mr. Wood he stated he would limit the current capacity of a line to 100 amperes. This, of course, means in general that the capacity of any one line is limited to a quantity considerably less than the 20,000 kilowatts frequently used, as only a comparatively small number of lines are operating at a potential of 120,000 volts.

Digitized by Google

I believe Mr. Wood stated that they used a factor of safety sufficient to allow for the falling of one wire. Is that on a single line, three-phase transmission. Does Mr. Wood allow more strength on a system which has two lines?

A point which is of interest to me in connection with the paper on irrigation prepared by Mr. Ensign, is, can any man pump under his property to keep the water level down and thus keep his own land from souring, or even use the water for irrigation? Can any man drill a well on his property and work on that basis? That may be a familiar question to a lot of people in this section but I am not familiar with anything covering that point.

J. H. Lighthipe: That question has been in the courts of San Bernardino County for ten years. They have dropped salt in one well and used chloride of silver tests half a mile below and injunctions have been placed on well after well. A man there would have a well flowing from 200 to 300 inches of water. They kept digging well after well, soon these would stop flowing and pumping had to be resorted to. Later he would have to go down twelve or fourteen feet. They went so low in one district that in some places the pumps are down in the holes 40 feet. The question of the ownership of subterranean water has been in the courts of San Bernardino county for a great many years, and it is in the courts there today. I don't think it has ever been settled.

Ralph D. Mershon: This paper states that greater trouble is had with low voltages than with high ones. Where such is the case, I do not understand why it should be, unless for the reason stated by the writer of the paper that the engineers have been so used to considering 15,000 volts a low voltage, in connection with which so little care is necessary, that they have not taken the requisite amount of care in the installation of it. In this connection I may say, it seems to me that in some cases high voltages are used where their use is not properly indicated. The design and installation of a high voltage transmission plant is an interesting piece of engineering work, but the adoption of a high voltage for this reason is not, to my mind, engineering. True engineering is based upon economics, and does not indicate the use of a high voltage except where it is economically justified. The object of using a high voltage, rather than a low, is, or should be, to save money. That is, to accomplish by the use of the high voltage something which can not be accomplished otherwise, except at greater expense. But it is certainly not economy, nor, from my point of view, true engineering, to adopt a high voltage, when, for instance, the saving in line copper by its adoption is more than offset by the increase in cost of insulators and transformers. In some cases where a high voltage has been adopted it would appear that economic considerations had not had any part in the decision to adopt it.

These considerations are of special importance in the case of some of the transmission systems in this country, which, instead

Digitized by Google

of being transmission systems pure and simple, are really high voltage distributing systems feeding a very considerable number of comparatively small customers. In such cases it may be much better to adopt a lower line voltage, with a higher cost of line conductor, in order to enable the system to serve small customers, that, at a higher voltage could not be profitably served because of the prohibitive cost of step-down transformers and controlling apparatus.

Referring to the question of lightning arresters. Very good success has been had in the eastern part of this country, and in many places abroad, with the horn type of arresters with graded gaps. That is, from two to four gaps on the same circuit, the gaps being of graded dimensions, the smallest gap having in series with it a high resistance, the larger gaps lower resistances, and the largest gap a fuse.

I can heartily recommend a careful study of the paper read by Professor Creighton at the recent Schenectady meeting of the Institute, which has to do with taking care of arcs to ground; and in connection with that paper the remarks made by Mr. L. C. Nicholson, and a previous paper by Mr. Nicholson relative to a method of protecting pin type insulators against the effects of arcs. The results obtained by Professor Creighton are very interesting, and Mr. Nicholson, who had previously been working along the same lines for over a year, has obtained, on the system of the Niagara, Lockport & Ontario Power Company, results even more remarkable than those reported by Professor Creighton.

There is a question I would like to ask Mr. Ensign. I appreciate that it cannot be answered definitely, but possibly he can answer in a general sort of a way. I should like to know from what depth he has found water can be profitably pumped for irrigation in this part of the country. Another question I would like to ask is as to the total depth of water required in irrigation in this part of the country.

Bearing on the point Professor Sorenson mentioned, the matter of unlimited pumping on your own land has arisen in the Transvaal, especially in the neighborhood of the Vaal River. As I understand it, there are at the present time laws in the Transvaal which prohibit the unlimited pumping of underground waters, because of the fact that by so doing you may rob your neighbor of the water under his land and required by him for irrigation purposes.

I do not entirely agree with Mr. Wood's statement that grounding the neutral of a three-phase system through a resistance results in an indefinite condition as regards the voltage to which the transmission line may be subjected. The voltage will be definite if the proper value be chosen for the neutral resistance. If the resistance be made too high there will be danger of oscillatory effects. But it is possible to adjust the resistance to a low enough value to avoid oscillatory effects, and at the same

Digitized by Google

time sufficiently limit the amount of current which can flow through the neutral. With such an adjustment the maximum voltage that can occur between a line conductor and the ground is something less than that which normally exists between the line conductors.

In the case of the system I have mentioned, that of the Niagara Lockport & Ontario Power Company, the neutral resistance has been chosen low enough to remove the possibility of danger of abnormal voltage, and yet high enough so that when the arc strikes from the cable, or its protecting metal, to the guard ring it will attenuate and go out, of itself, unless, due to wind, or some other condition, it elongates enough to produce a short circuit between line conductors, in which case the automatic mechanism, provided by Mr. Nicholson at the station, operates and extinguishes the arc.

O. H. Ensign: I want to answer a question that someone has raised, Mr. Cory, I believe, about the permanency of the work shown in my paper, in connection with Mr. Lighthipe's experience. It would have been better for Mr. Lighthipe to have had a concrete caisson with pump suspended from the top. Much of the history of the southwest shows a lack of foresight in doing the work in the first instance so as to anticipate conditions one could not forsee because of the short period of experience with the physical conditions of the country. The form of plant described in the paper can not be put out of commission by any probable variation of the water plane.

There are a number of pumping stations where this same thing has occurred, where they have followed the water plane down as the water plane sunk, and got their pumping plant down and could not get it out or use it when the water returned. Having had that in mind, and having had a great deal to do with the development of underground water before I entered the Reclamation Service, we were able to take advantage of that experience in the first plant for which we were responsible. This was the Pima Indian Reservation, which is described in the paper. In this type, you have a well that will last indefinitely. If your water plane does fall, you can still go on further until you reach the point which has been questioned as to the practical depth at which you can lift water for irrigation. That is a question of the nature of the crop and the time and amount of the rainfall that you have in any location.

I have mentioned in the paper that in this valley, Southern California, water is apparently lifted 200 ft. successfully for oranges. I want to qualify that, because the successful growing of oranges is a very indefinite term. A great deal of money is made by a great many people who know how. I honestly believe that you can afford to lift water with economical apparatus something over 100 ft. after you have acquired the grove and it has become a producing property. For the growing of alfalfa I question whether it is profitable to raise water over 30 ft. in

Digitized by Google

small plants even where we can cut six crops per annum, as we do at Yuma and Salt River and some other places. All these things vary, and every community has its own economical points which have to be watched before one goes too far, and it is a very broad and indefinite problem.

The question as to the right to pump underground waters. I believe, that the courts have said in Southern California that you can pump on your own land almost in every case, provided you do not send it off on to somebody else's land and sell it. I believe that is the interpretation of the law. Somebody had better correct me if I am not right on that. But it has been decided that you cannot develop water and transmit it for a general irrigation system in Southern California when that injures prior right. I am not up in law, but that is my memory of one or two cases that have come to my notice.

In the first part of the discussion, the question was asked what to do with the power in the non-irrigation season. That almost solves itself. In the first place, most of the reclamation power plants, Minidoka being an exception, however, are derived from the water which is used for irrigation; that is, the water has been or is being diverted. If it has been stored, it is let out only as needed during the irrigation season, (or it was not worth while to build the dam), and the power so developed of course is used at the same time as it is then wanted for pumping for irrigation, and the two needs exist together and work together as one problem, and in many cases there is no winter pumping to be done at all. It may occur again that there are other power plants on the project for instance, the Salt River Valley Water Users Association have agreed to put up a certain sum of money to build on that project certain power plants, which are made possible by the irrigation works, and with the idea of using them for revenue from the sale of power. The Roosevelt plant was built primarily as a pumping power plant only, although there was existing in the Valley a contract with one of the old irrigation companies with the electric light company in Phoenix, which had to be taken care of, and it has 20 years yet to run. The Reclamation Service is now selling them power from the Roosevelt Dam, but this will be shut off when water is not needed from the dam as soon as these other plants in the valley are built, which are now under contract, and they will use the natural flow of the Verde River and the irrigation water which flows through the canals and are to be located on drops in the canals. Ultimately there may be developed something like 8,000 h.p. besides the power of the Roosevelt Dam.

Something has been said of the capital cost. The capital cost of the Minidoka plant is about $18 per acre so far as the actual power plant, transmission lines and pumping stations, are concerned. The $40 which I mentioned (and which has not been announced as such, but is somewhere in that neighborhood), is the cost of that portion of the project interest in the dam

Digitized by Google

which diverted the water in the first place, and the cost of power and pumping, distributing systems, turn-outs, and all other parts of the system.

Now, there are a number of projects in the United States built by private corporations, and some by the Reclamation Service, in which gravity systems have cost more than that.

Ralph D. Mershon: In figuring these costs, do they include the interest on money during the construction of the dam?

O. H. Ensign: The Reclamation Service is financed by the money received from the sale of government lands, and is loaned without interest to the people who are to pay for it ultimately, the Reclamation Service acting as a trustee, as it were, using this fund, building these works which the people pay for in ten annual payments after the works are finally completed and the cost is known. So the interest is not charged into this cost. They pay no interest on the money whatever. It is mentioned in the paper that there is no interest charge on the money.

The primary idea of the irrigation law was to bring into some degree of value many areas in the west which were beyond the reach of private capital—that is, to irrigate them. I do not believe you could have interested any banker in any sort of irrigation securities in 1902 and 1903. I have heard it stated on reliable authority, and I believe it is true, that up to 1902-3, no private irrigation corporation had ever paid interest on its bonds. That may not be exactly so, but it is nearly so. Very few of them were successful from the standpoint of the investor. The primary cause of that was lack of knowledge of the run-off of the various watersheds in a new country and a lack of interest in the promoter in making sure what that run-off was, and an effort in almost every case to cover more land than the run-off would take care of. They incurred expenses to deliver water, made contracts for water, and sometimes a rather wild finance scheme was attached to the plan, and left the irrigator with a chance to reclaim a portion of the area contemplated if he took hold of the property on the basis of his riparian rights to take care of himself and build it, as in many cases has been done. But the man who put his money into it as an enterprise from which he expected to get revenue, I might say, nine times out of ten received nothing. And the irrigation law came out at that time with the idea of correcting that situation, of bringing together some of these into actual success.

The Salt River Valley presents the most startling fact in that connection. When the Reclamation Service went in to build the Roosevelt Dam, the Valley had been unsatisfactorially served by private corporations. The Salt River is a torrential stream, probably one of the most torrential in the country. I myself have seen it rise from 500 second-feet to 150,000 second-feet in a few hours. It is quite an undertaking for any private capital to build a dam on such a stream. Since the Service started to build that dam, enough water has passed the site to

Digitized by Google

fill it eight times. Just before President Roosevelt opened it, 250,000 acre-feet were stored in it in one day. Floods have passed which would have filled the reservoir in twenty-four hours, and it holds enough water to cover a strip a mile wide and a foot deep from San Francisco to Detroit, Michigan. That is about the best way I can give it to you so you will remember it. It contains 1,300,000 acre-feet.

The Reclamation Act provides that the Secretary of the Interior shall take the funds arising from the sale of public lands and use them for the creation of irrigation works. Practically the only restriction is that no man shall hold over 160 acres of land. If he can make a livelihood, or keep himself busy on less, he shall not have any more land than necessary to support him and his family profitably. In some places it is forty acres; in some places it is eighty acres; Minidoka is eighty; at Yuma there are some places where they think of dividing it up into twenty. The former has ten years to pay for the works in. After the work is complete and the costs are known, the cost is assessed to the land, and liquidated in ten annual payments, plus the actual cost of maintenance and operation during that period, paid by the farmer. In a case like the Salt River, where practically 90 per cent of the land was settled, the government places what amounts to a mortgage on the property to cover the cost before work is begun. There has been a great deal of talk about its being a land speculating scheme where there was no government land the land being already settled. In Salt River Valley they had made effort after effort to control that turbulent stream with continued loss to themselves. Therefore, it was more of a God-send than a speculating scheme that the Reclamation Service could take up the work in the Salt River Valley and make it one of the solidest communities in the whole West.

Coming to this question again of the sale of power, at the Minidoka project, we have an entirely different proposition than we do at Salt River, where we have no real right to generate power except for pumping purposes, except such surplus as may pass the Verde at flood stage or other run-off periods. At Minidoka we have to pass something like 3000 second-feet to the water rights below, during the irrigating season and the remainder of the time the minimum is about 5000 second-feet. In order to keep the operating force the year around and to reduce the all around yearly cost of pumping we are selling power at a very low rate to the several small towns which have sprung up on the project. We are selling this power to those towns at a very low rate in order to bring the towns into a better condition and in order to make them more agreeable places to live, as it is a pretty rugged country in the winter, although a very productive and delightful one in the summer. We hope to build the load up, and are today encouraged that we shall more than pay the operating expenses of the plant during the period it is not

Digitized by Google

operated for pumping. The irrigation season is possibly from the 15th of May until the 15th of October. We have started one season on the 15th of April. In order to get a load that was reasonable from the use of power in the communities, or small towns, we have undertaken to do some heating there. We are selling heating current at a price, I am almost ashamed to mention. But the people themselves, having built these plants with their own money and owning them, and having to stand behind the operation, the prices are not unreasonable. The prices for light and power are just about the same as the adjacent towns. We are selling power for heating at $1.25 a kilowatt a month at a flat rate.

As to the question of developing power and selling it, to reduce the operating cost of the project that has not been authorized. There was a bill passed Congress authorizing the Reclamation Service to sell power, or contract the rental of power sites, up to the limit of ten year contracts. We have under way several construction plants of from 1000 to 1500 kilowatts. They will be used in the construction of dams, and when finished they can be used for whatever purpose desired by the Water Users Association which has paid for these plants in paying for the other works. Undoubtedly there will be found a market for the power and in most cases it will be used largely for pumping.

One or two questions have been asked that I can best answer in a general way by the way we attempted to handle the irrigation pumping problems in this country in the early days of transmission. The first irrigation pumps were started on a 16-hr. basis. Some of them had the privilege at a higher rate of staying over the peak load provided they would cut off on telephone call. That is what is meant by the off-period that has been spoken of, that irrigation may be built up and the valley in the load curve built up and a profitable revenue from that source obtained. There has been one disappointing thing about it. Some seasons were wet seasons, and it would be necessary to shut off irrigation for a long time. In some seasons it diminished to one-half. It is not a load that can be entirely relied upon.

R. J. C. Wood: Mr. Babcock asked at what distance you should switch over from approximate formula to accurate formula in calculating transmission lines. There is no one particular distance where you leave one and get into the other, because they diverge from each other gradually. I would say that up to 150 miles you can use your approximate formula. After you get over that, you had better check it by the correct formula.

He also suggests that more than one conductor may go down at a time. Most of our experience has been that when we get in trouble on the line it is from one conductor to the tower, and it is not between wires; so the switchboard man up in the generating plant, as soon as trouble comes, at once shuts off the current and saves the other wire. The other wire is not involved; there is only one wire involved.

Digitized by Google

Mr. Downing agrees with me as to the automatic regulator at the generator end, and he states that it is cheaper to install synchronous apparatus than a lot of copper in the line. I believe that is so.

I said there were certain charges necessary more as a statement of fact than as an objection to the system of using synchronous apparatus.

In regard to limiting the capacity of circuits to 20,000 kilowatts or 100 amperes, I think it is the general opinion that it is the number of amperes you break in the switch which does the damage. Possibly basing the switch capacity on amperes is a little better than basing it on kilowats. Mr. Mershon says he was astounded at there being more trouble on low tension than high tension. It may be because there are more miles of the low tension wire that you get more trouble coming in through it, in addition to the fact that it is not built so carefully. I notice he got good results by having resistance series. I suppose you have got to hit the mean between running an ungrounded high tension and a high tension connected solid with the ground. If you are connected solid to the ground you limit your tension on one wire. Can't you put resistance between the neutral and ground? You don't know what you are going to get on that line. The neutral point will shift around and you may get all kinds of voltage, because if the resistance is low, that would indicate the resistance. If the resistance is too low, that will not bother your current. You have to know just what you want.

Digitized by Google

DISCUSSION ON "A POWER DIAGRAM INDICATOR FOR HIGH TENSION CIRCUITS," LOS ANGELES, CAL., APRIL 27, 1911. (SEE PROCEEDINGS FOR APRIL 1911.)

(*Subject to final revision for the Transactions.*)

E. F. Scattergood: I understand that this instrument is quite easily moved and therefore available for investigations in the field and I would like to hear something further in regard to the portability of the instrument. I feel that the profession is greatly indebted to Professor Ryan for the instrument which he has developed and presents as well as for the practical results he has secured from its use and presented by him last January.

C. L. Cory: I think you will agree with me that as Professor Ryan outlined to us the details of this instrument we enthusiastically admired the manner in which the result has been accomplished. Professor Ryan stated that in general the measurement of one watt at 100,000 volts is of little consequence in the practical operation of transmission systems. However, we are interested quite as much in being able to measure the indefinitely small quantities here indicated as we are in the accuracy of the measurement of the quantities ordinarily of interest in such systems. In his experimental work he has measured power at 9,000 volts amounting to only 0.03 of a watt. This would correspond at unity power factor with a current of 1/300,000 of an ampere. We are with this instrument capable of measuring the three hundred millionth part of the output of a modern 3,000 kilowatt steam turbine alternator, and it is quite as important sometimes to be able to measure these very small quantities as it is to accurately measure the larger quantities.

The instrument allows a beautiful analogy to the steam engine indicator. We have a horizontal line on the bottom which corresponds to the line of atmospheric pressure. We have a vertical line which corresponds to the variation of pressure. In Fig. 7, where the pressure approaches 40,000 volts, the diagonal line shows no energy. Beyond this the two areas, one larger than the other, indicates at which point the "thing turns around the corner", so to speak. The instrument is one which it seems to me will have wonderful practical application. We have had indicated to us directly how insulators may be tested and I dare say we might quite as well use it to determine the dielectric constant of condensers. It is applicable to ordinary voltages quite as much as it is to our highest practical voltages. After all, that which is probably the greatest attainment, however, is the beautiful and accurate method whereby it is possible to measure accurately on the very highest voltage systems the smallest possible quantities and in addition to ascertain what is happening on the line as a result of the action of such small quantities of energy.

J. J. Frank: I see practical value in the use of this instrument in measuring losses at high potentials. At present we have no satisfactory means of measuring such high potentials because our instruments do not follow the variations in the

Digitized by Google

wave-shapes of potentials. The only instrument we have is the spark-gap.

If this instrument of Professor Ryan's does recognize the wave-shape, it will certainly be of value in measuring losses on lines, in cables, dielectrics, oil and insulators, which is one of the important studies we now have before us in connection with high voltage transformers.

Ralph D. Mershon: Professor Ryan spoke in a very off-hand way of getting a known high voltage load with which to calibrate his instrument. I have often endeavored to get such a load that would be above suspicion, but have never succeeded. If Professor Ryan has devised some means of getting a high voltage load that will remain constant, and can be accurately measured, I shall be glad if he will tell us of it.

I should like to ask Professor Ryan whether he has investigated, by means of this instrument, the effect of moisture on the corona.

I desire to take this opportunity of expressing my appreciation of this paper, and my admiration for the work it evidences. With Professor Cory, I think the sensitiveness and accuracy are most astonishing, and should lead to extremely valuable results. An instrument of this sort should be well adapted to the study of insulation and what happens when it is subjected to electrostatic stresses. At the present time our knowledge in regard to dielectrics is comparatively limited. I believe one of the greatest problems before the Electrical Engineer today is the problem of insulation; that there is a possibility for great improvement over what we have now. What we would like to have, is an insulating material that can be worked like metal, and that will stand the temperatures most metals will, so that we can run our apparatus at something like the temperature of a steam engine. It seems to me, the further we get away from organic substances the more nearly will we approach a satisfactory solution of the insulation problem.

H. J. Ryan: I will take these questions up in the order in which they were given. As to the portability of this apparatus: In its present stage of development it is not very portable. An American instrument maker is now investigating it with a view to placing it on the market in a portable form should that be found practicable. In 1901 I transported an outfit of substantially this same sort from Cornell to Columbia to operate it magnetically as an oscillograph at the conversazione given by the American Institute of Electrical Engineers. In 1905 I again transported a similar, though a much more complete outfit from Ithaca to Pittsburg to deliver an illustrated lecture at the Electric Club on the uses of the cathode ray oscillograph. Those two experiences demonstrated that the outfit referred to in this paper can be considered as portable equipment, though it is certainly a long way from constituting a portable instrument in its present form.

Digitized by Google

I began ten years ago to look for a feasible electrostatic power diagram indicator. My great regret now is that largely through a feeling that such a thing was perhaps impossible, I failed to realize that I had at hand all the while the necessary expedients. These were employed just as soon as the principles were worked out upon which the power diagram indicator must operate.

Referring to Mr. Frank's question as to whether this instrument will recognize wave forms—it will do that very nicely. Alternating voltage applied between one pair of quadrants only will cause the ray-pointer to oscillate and the true voltage wave form may be observed by looking at the band of light thus produced on the screen. To do this transmit the image of the moving spot to the eye through the usual synchronous vibrating mirror. If preferred the ray-pointer may be given a sine-wave motion in quadrature with the motion imparted to it by the voltage. Thus an open card is formed of a known and an unknown motion. In that way the unknown voltage wave form that imparted the corresponding motion to the ray pointer becomes known. We can all realize this by remembering the steam engine indicator card. There the horizontal motion being reduced from the piston motion is known. The vertical motion produced by the steam pressure is unknown until the indicator card is produced by combining both motions when it is made known also. A sine wave current for this purpose is obtained by means of a " wave filter " described in my paper on the cathode ray oscillograph read at the 1903 Niagara Falls meeting. The ray-pointer is actuated magnetically by such current. If you are making accurate measurements of this kind, you would have to go into a careful arrangement of the electrodes mounted on the walls of the tube in order to make the spot deflect accurately in all regions; that is, to make the quadrature deflections in all regions proportional to the applied potential differences. That means not using a plate bent around the tube for the electrodes, but using parallel wires and distributing them around the tube until the electric field therein is entirely uniform within the range in which you are using it. For all ordinary work the quadrant will not have to be given such special construction.

As to objection to the internal losses in the high-tension circuit of the transformer when you apply the velocity to the condensers at the center of the same, instead of at the center of the samples: If the oil is clean, newly treated, has not been in the service, you will not find a loss such as you may expect. If, however, the transformer is not in this condition, *i.e.*, the oil has not been treated and put into proper condition for a test of this kind, then you obtain an area there that, under some circumstances, I am pretty clear could be cared for by subtracting; but it was on that account that I went after this method of using the sample itself only that is by working at the center of the sample. (See Fig. 8.)

Replying to Mr. Mershon's question as to what extent we

Digitized by Google

may use this instrument for measuring high-tension line losses due to inphase current through the atmosphere—*i.e.*, corona formation.

We made some use of the instrument for corona loss measurements and have found that it does very well for such purpose. Measurements of sub-corona atmosphere line losses are difficult always because of the low power factor present. The instrument as it stands in this paper is at a corresponding disadvantage. When the power factors are small, one to two per cent, for example the corresponding power card is inconveniently elongated. To obviate this difficulty we have tried out an arrangement of velocity condenser that makes use of some of the line voltage for compensating the elongating effect of the reactive power. We found that this can be done and that wider cards can thus be obtained to indicate losses that occur at very low power factors and which otherwise would produce long narrow inconvenient and correspondingly inaccurate cards.

As to the axes not being at right angles in Fig. 6, that is due to the fact that our original try-out tests were just to see whether the thing would work. This was all done last spring. If we had had any notion in advance that the method would have worked out in this way, we would have taken a little more care. The quadrants were held to the outer walls of the tubes by rubber bands; they did not produce electrostatic fields that are exactly at right angles to one another because no effort was made to adjust them with exactness. These try-out integrity tests were made with this careless mounting of the electrodes, for the reason that I thought the apparatus would go into use, if at all, as something that we could bring together with comparative ease. As a matter of fact, it turned out much better in this respect than was anticipated. I did not have the time to make special tests for this paper, but took the tests which we had made in our former work. They are just as they were made in the original trials when we undertook to see how the method would work.

C. L. Cory: I would like to ask Professor Ryan if the fundamental work has not already been done to a sufficient degree so that we may very properly anticipate the use of this instrument, properly installed in commercial shape, in a substation for instance, so that experiments may be made on long distance transmission systems at different frequencies from 20 to 60 cycles and at different voltages from perhaps 30,000 up to 150,000 volts, not only on transmission lines which are practically level but on those crossing mountain ranges in which the different parts of the line are subject to atmospheric conditions which vary with the altitude.

What I am trying to bring out is the practicability of the instrument to determine questions not heretofore capable of satisfactory treatment.

Is it not true that the results to date indicate the possibility

Digitized by Google

of the use of the instrument permanently installed in a substation for experiments on long lines in place of the one only 100 feet in length as used in your laboratory.

H. J. Ryan: I think that can be done. I believe, for my own part, it will be reduced to such convenient form.

R. W. Sorensen: Am I correct in my understanding that with an arrangement such as is shown in Fig. 23, the indicator can be used for measuring the core loss occurring in the transformer shown as load.

H. J. Ryan: The method given in that figure is for low-tension work entirely and it was put in here to round out this general scheme. If you can get a proper inductive control of the current in the circuit " L " then the area of the card should be proportional to the power that is applied to the circuit. The ray-pointer will then have a velocity proportional to pressure and not proportional to current; and it will have a displacement proportional to current.

R. W. Sorenson: In Fig. 8, for instance, the sketches marked " T ", etc., I presume are parts of a transformer.

H. J. Ryan: That is correct.

R. W. Sorensen: Would you measure on the transformer the loss due to the dielectric hysteresis, if the pans containing the oil sample were removed?

H. J. Ryan: If the sample were disconnected the ray-pointer would be given no velocity displacement, it would have a pressure displacement. A band of light would be formed on the screen due to such displacement being proportional to the terminal voltage of the transformer.

R. W. Sorensen: Then in Fig. 4—what would we get there, that we would not get with connections like Fig. 8, with the sample pans of oil left out.

H. J. Ryan: In Fig. 4 with no test specimen or other load connected the ray-pointer would be given a velocity movement proportional to the internal capacity charging current of the transformer and it would be given a displacement at right angles to such velocity proportional to the transformer terminal voltage. The result would be a card that would constitute a certain kind of measure of the high voltage dielectric loss in such transformer.

R. W. Sorensen: The reason I asked these questions was that about two years ago I tried to find out what was happening in a high voltage transformer. That is, it seemed to me, according to some work we had, that there is always a certain amount of energy transmitted through the dielectric. In some instances, it does not amount to much. In the case I have in mind the transformer happened to have four sections. When those four sections were in series, there was three to five per cent more core loss by test than when those windings were broken up in sections. I said the greater part of that must be dielectric hysteresis loss. What I am getting at is, can we measure with

Digitized by Google

your instrument the dielectric hysteresis loss only and thus eliminate the error of subtracting one large quantity from another to get a small one as was done in the test to which I refer?

H. J. Ryan: If you lay the case of the transformer open, even in the California climate during the summer, it will show you, in a hurry, a nice fat card.

R. W. Sorensen: But it measures only the hysteresis loss; and not any other losses?

H. J. Ryan: Yes, it measures only the dielectric hysteresis loss. Certainly such is the case after subtracting the $I^2 R$ loss that occurs in the high tension winding due to the circulation of the internal capacity charging current. Unless the oil is in the very best possible condition such dielectric loss, we have found may be considerable.

Digitized by Google

DISCUSSION ON "TENTATIVE SCHEME OF ORGANIZATION AND ADMINISTRATION OF A STATE UNIVERSITY." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions.)

A. H. Ford: The Institute is to be congratulated upon having a paper of this kind presented to it for consideration. Among the papers dealing with educational subjects, presented in the past, have been those by practicing engineers indicating the kind of training which the young engineers whom they employ should have and those by educators saying that it was impossible to give such a training. Now there is presented to us a problem of organization on which it seems as though the engineers and educators might agree, as the problem of organization is essentially the same no matter whether the product is electrical energy, dynamos or trained men.

As the scheme of organization presented by Mr. Mershon does not differ materially from various schemes now in operation the speaker will point out some of the defects of the present systems.

First: The fixing of authority is indefinite, particularly as to distinctions between management and administration; with the result that frequently the board of trustees decides on matters of administration concerning which it has insufficient knowledge to act intelligently. The natural result is that the administrative officers are unable to maintain a definite policy and consequently find it difficult to obtain proper coöperation of those under them.

Second: The making of the secretary, or other financial officer, responsible to the board of trustees instead of to the president gives rise to a two headed organization which frequently results in the control of the educational policy of the institution by the secretary, through his control of the budget. This is because the board of trustees naturally looks to the secretary rather than the president for advice regarding financial matters and decisions regarding the amount to be paid for equipment and professors' salaries have a material affect on the educational policy of an institution.

Third: The activities of the students outside of the class room ordinarily receive little attention, with the result that many students when freed from restraint in this way acquire habits which make the ordinary routine of business irksome. This is no doubt the cause of the frequently repeated remark that a college graduate is of not much use in the business world until he has been away from college for two years.

There are two provisions in Mr. Mershon's paper which stand out prominently. The alumni advisory board and the method of fixing a budget to be presented to the board of trustees.

An alumni advisory board of the kind contemplated should prove very useful; but it should not have the duty of confirming appointments to the teaching staff for such appointments frequently require confirmation with great despatch and cannot wait

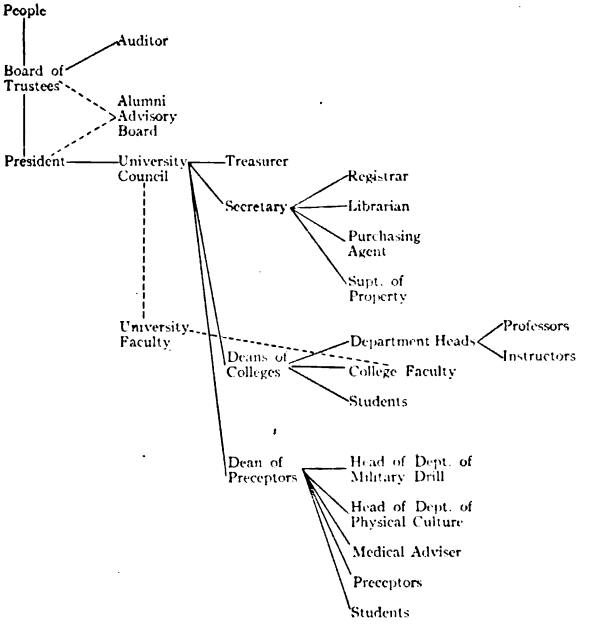
Digitized by Google

for the assembly, on call or at a regular meeting, of such a large body as the alumni advisory board.

The method of fixing a budget to be acted on by the board of trustees is admirable and should do much to overcome the bad effect of having the secretary report directly to the board of trustees.

The following plan of organization, shown in Fig. 1, is suggested as a means for overcoming the defects noted. The duties of the various officers are given only where they differ from those in the plan proposed by Mr. Mershon.

Board of Trustees. The board of trustees is the direct repre-



Solid lines indicate subordinate relations. Dotted lines indicate advisory relations.

sentative of the people and as such should dictate the general policy of the university and represent the university before the legislature. Being nearer the people than the members of the faculty the members of the board of trustees may see fields which could be profitably covered and which have escaped the observation of the faculty. It should not burden itself with details of administration but should confine its activities to such large matters as determining the general policy of the university, appointing the president, confirming the appointment of deans and other officers of equal grade, passing on the budget and approving plans for new buildings.

President. In addition to the powers and duties named the

Digitized by Google

president shall, on the advice of the university council and subject to the confirmation of the board of trustees, appoint the deans, secretary and treasurer.

University Council. The university council shall consist of the deans, the secretary and the treasurer. The secretary shall be secretary of the council. The secretary and the treasurer are added to the council in order to have their advice in matters which involve the expenditure of money or which require a knowledge of the past actions of the council or any of the faculties.

Secretary. The secretary shall have charge of all records of the university except those relating to finances and shall be secretary of the university council and of all faculties. He shall appoint all his subordinates subject to the confirmation of the president.

Treasurer. The treasurer shall have charge of all moneys and credits and shall keep a record of all financial transactions. He shall be the bursar of the university.

Deans of Colleges. In addition to those duties mentioned, the dean of each college shall appoint, subject to the confirmation of the president, all officers of instruction in the college.

Dean of Preceptors. The dean of preceptors shall be responsible to the university council and the president for the conduct of the students when outside of the class room. He shall have supervision of all student organizations and shall see that the accounts of such organizations are audited by the auditor of the university. The departments of military drill and athletics shall be under the dean of preceptors.

College of ..... Each college shall be organized into departments, each of which shall be in charge of a professor who shall also be director of research in that department. Under him shall be such associate professors, assistant professors and instructors as may be necessary for the proper conduct of the department.

Preceptors. A preceptor is a person of the rank of professor or assistant professor who has charge of the students at such time as they may be outside of the class room. He shall act as their confidential adviser and shall give them such advice as to methods of study and conduct as may be desirable. There shall be at least one preceptor for each 50 students lodged in the university dormitory. He shall be head of the house and as such shall see to the proper enforcement of the dormitory rules. The different use of the term preceptor from that of Mr. Mershon is to be noted. It is not intended to limit the activities of the preceptors to such as are concerned with those students who live in the dormitories; but each student in the university, is to have a preceptor who shall be in *loco parentis* for that student, the number of students assigned to a preceptor being small enough so that he may become personally acquainted with each.

Medical Adviser. The medical adviser to students shall have the rank of professor and shall be under the dean of preceptors.

Digitized by Google

His duties shall be the giving of medical advice to students but shall not include treatment when ill. He shall also advise the dean of preceptors in regard to matters affecting the health of the student body.

Registrar. The registrar shall keep a record of the academic work of all students and perform such other duties as may be assigned him by the secretary.

Librarian. The librarian shall perform such duties as usually appertain to that office and in addition shall be superintendent of university publications other than announcements and those of like nature.

Superintendent of Property. The superintendent of property shall have charge of all property of the university except moneys and credits and the erection of all buildings. He shall report directly to the secretary.

Purchasing Agent. All purchases made for the university shall be made through the office of the purchasing agent. He shall report directly to the secretary.

University Faculty. The university faculty shall consist of the members of the university council and all persons on the university staff having the rank of professor or associate professor. Assistant professors shall have seats in the university faculty but shall not have the right to vote.

The university faculty shall be the legislative body of the university in all matters relating to the student body, entrance requirements, graduation requirements and such other requirements as affect more than one college.

College Faculties. Each college faculty shall consist of all the members of the college staff above the rank of instructor. The instructors shall have seats in the faculty but shall not have the right to vote. The college faculty shall be the legislative body of the college in all matters of a pedagogic nature and shall be the final authority in fixing the courses of study.

Auditor. The auditor shall be the direct representative of the board of trustees and as such shall audit the accounts of the treasurer and act in an advisory capacity to that officer. He shall also audit the accounts of all student organizations.

C. F. Harding: For a number of years we have had before the Institute and other conventions considerable discussion of the technical university and its product—by technical men in manufacturing institutions and in the engineering field in general. It seems to me that this is a very healthy condition of affairs. It would be too bad, if the manufacture of an article should be entirely neglected by the consumer of that article, and it is equally serious if the output of the technical university is entirely neglected during the university period by those in charge of the corporations to whom the university graduate is going. I am particularly pleased, therefore, to congratulate the Institute, upon the papers which it has had in past years and upon the very general discussion, which has been entered into by those

Digitized by Google

in charge of university departments and by the engineering profession generally.

The paper which we have this year I regard as confined largely to the organization and administration of the university, and not to those points which, it seems to me, are most vital in the development of the technical graduate, namely, the curriculum and the administration of that curriculum in class room and laboratory. I wish, therefore, the discussion could be broadened out and not limited to the rather narrow question of university organization and administration. If this plan were put in vogue and standardized in the various universities we would not be benefitting, in my opinion, the output of these universities. We would be expediting the business of the university, and possibly indirectly, through the alumni advisory board, improving the output to some extent, but it seems to me that the discussion and the resulting changes in the curriculum, and in the administration of that curriculum in class room and laboratory, would yield very much greater results. Limited as we are, however, to the organization and administration of the university, there are one or two things I wish to say along the lines of this paper.

The university organization could be, in my opinion, quite similar to the organization of an industrial corporation. I see no reason why it should be materially different from such an organization. I do not see, however, how such an organization can be standardized for a number of universities, particularly state universities, where local and legislative conditions are bound to limit such standardization. Nevertheless, if we cannot have a standardized organization, as this paper infers we may have, I think we can gain from this paper a great number of valuable suggestions which can be picked out and applied to the organizations of the various universities.

The most radical departure from the present organization of most universities as has been stated, is probably the formation of the alumni advisory board, and it seems to me that this is directly along the line of coöperation between the university and engineers and manufacturers in the field, which, as I stated at the beginning of my remarks, is of so much value. If the alumni ten years out of the university, who have been through that university, know its problems, who have been through ten years of practical and professional experience, can be brought into vital touch with the organization of the university, it seems to me that this coöperation which I have spoken of so favorably, would be greatly enhanced, to the ultimate benefit of the graduate of that university not only, but to the prestige of that university as well.

The formation of such an alumni advisory board as has been suggested in this paper, while beneficial, as has been stated, would, if carried out in detail as suggested here, greatly cripple, to my mind, the business of the university. I believe that such

Digitized by Google

an advisory board, if organized at all, should be a fairly representative one, should include engineers from all branches of the profession, and from all parts of the country, and, therefore, with a board of twenty of such men, it would be extremely difficult to get them together at a single meeting sufficiently often to enable them to carry out the duties which have been imposed upon them by an organization such as we have in this paper. To reduce these difficulties, without introducing any serious disadvantages, it would be possible to reduce the number of such an alumni advisory board by a large majority, from twenty to four or five, and to limit its jurisdiction to the purely advisory duties as suggested here, with the exception that they should advise, not with regard to the appointment of all the members of the instructional board of the university, but the heads of departments, heads of schools, and deans. Now if the alumni have an active part in suggesting the heads of departments and deans, and if the election or appointment of the subordinate instructors is left to the heads of departments and deans, the up-to-dateness of the faculty, if I may use that word, will be maintained. I assume it is largely that quality which the author of the paper wishes to maintain in the faculty—the prevention of the faculty from getting into a rut, as is often the case, and becoming out of touch with practice, and therefore becoming a detriment to the output of the university. If this alumni advisory board can be limited in this way, it seems to me it would be a great improvement, not only over the present condition, but over that set forth in the organization mentioned in this paper.

I regret that there are comparatively few of the engineers in the field here today, as I had hoped we would have an active discussion from these men. I believe they are the men with whom we should coöperate in turning out the best and most efficient product from our technical universities.

B. B. Brackett: I believe thoroughly that the administration and management of our universities can be improved, and I believe that they can be improved by the advice of those who are outside. I have no patience with those who maintain that the university is a world by itself, and is subject to its own laws and its own rules, methods of management and government.

We are to be congratulated in having this subject brought up. But I do not like the author's uggestion of an alumni advisory board that might be a controlling factor. As I understand it, his alumni board must approve all appointments, and in that way it would possess real veto powers. To my mind there are serious dangers in such a plan. It is possible that it might lead to results quite the opposite of those suggested by the last speaker. You cannot have an alumni board, unless that alumni board is elected by the alumni. Are the representatives of the alumni likely to be any more expert in educational or technical lines than the average member of the alumni association? Is the

Digitized by Google

average alumnus of our colleges and universities an educational expert? Is the average one well enough informed to take part in the management of a university, to the extent of saying who should be on the faculty or who should not?

In comparatively recent years, two of our well known universities have had radical upheavals in management and internal organization. In both cases investigation will show that the alumni were with the old order of things and not with the progressive element. There is a possibility of an institution being away behind the times, in the ability of its faculty, its general organization, and the character of its work. And it is possible for the mass of the alumni to think that this institution is one of the best in the world. In fact, it is quite natural for them to think so, and to stand as strongly as they can for the old order of affairs.

An alumni board with such influence in the appointment of faculty members might foster excessive inbreeding in the personnel of the faculty. In fact there are many possibilities of obstruction to real progress in an alumni board with powers so unusual as those proposed by Mr. Mershon.

The dangers would be especially great in the case of those institutions that have not yet reached true collegiate standing.

A. S. Langsdorf: This paper brings to mind that the study of organization and administration in university work was taken up some time ago by the Carnegie Foundation for the Advancement of Teaching. The investigation, which was made by a mechanical engineer, had for its particular purpose the study of methods in teaching physics. Attention was confined to one subject because of the obvious impossibility of considering the entire field in the time allowed for the work. The results have been published by the Foundation and are available to all who are interested. The report met a rather cool reception and even ridicule, especially from college men, because of certain unique suggestions which imposed factory methods upon the methods of training students.

Mr. Mershon's paper seems to be actuated by the same general motive which prompted the Carnegie Foundation in its undertaking, namely, the conservation of energy in administering purely routine affairs of university work. It would seem that many of the plans outlined by the author should be self-evident to executive officers of reasonable efficiency, always supposing that political conditions (in the case of a state institution) are what they should be. But the question that is likely to present itself to those in the educational field, after reading the paper, is: Where is the Faculty? Its functions, which should be of the greatest importance in a democratic institution like a university, are apparently submerged and made subordinate to those of unduly exalted executives.

I believe with one of the previous speakers that the powers of the alumni council as proposed in the paper are too great.

Digitized by Google

Alumni in general are not well acquainted with college affairs, especially after an asbence of ten years or more, and there has been a tendency on their part, particularly in the case of state institutions, to meddle in certain features which were better removed from their influence. I refer to their rather pernicious activity in athletics, in which they have frequently exercised a decidedly corrupting influence. But granting that an alumni council of the best type could be secured, its presence would seem to violate a fundamental precept in efficient management by a further division of responsibility instead of a concentration. Instances could be mentioned—such as student "strikes"—in which the interposition of an alumni body between students and faculty would have been a real calamity.

George D. Shepardson: I have tried to orientate this paper with reference to the work of the American Institute of Electrical Engineers, and I confess difficulty in orientating my own ideas with reference to this paper. In attempting to find the relation of the electrical department to the proposed organization, I confess embarrassment. On the other hand, it seems to me that the paper might have begun further back. Considering the problems which a state educational institution has to face, we find that almost without exception the public resources of the state are scattered. In almost every state instead of there being one State University, which should be at the head of the educational system of the State, there are several institutions. Even though the state university is nominally at the head of the state public educational institution, in every state certain parts of the system are outside. Minnesota, for example, has been pointed to as a state in which the entire educational system has been built up symmetrically by having the high schools point up towards the State University, and at first sight it looks like an ideal situation. There are, however, a number of normal schools whose purpose primarily is to train teachers, and which have no thoroughly specified connection with the university, but which every now and then agitate the question of extending their work and granting degrees. There are certain other branches of education which are under state auspices, and yet which do not quite fit in with the ordinary scheme, such as institutions for the blind, or for the deaf, or for the feeble-minded, institutions which too frequently are classed along with the penal institutions. In almost every state we find several governing boards which have to do with educational institutions and when it comes to the legislative sessions, whence come the appropriations, there are a number of different boards generally in sharp competition with one another, or else in some unholy alliance which is not of the best order.

One of the fundamental features which should be included in any general scheme of reorganization, is some provision for harmonizing all public educational institutions in the State. In the State of Ohio, for example, I believe there are four,

Digitized by Google

certainly three, different institutions for higher education that enjoy the receipt of money from the State Treasury, and in almost any other state that situation exists to some extent. It seems to me the greatest need of our state universities is that the entire educational system of the state should be unified. This is much more important than that the university organization itself be overhauled. Another difficulty with the proposed organization is that in most of the states the universities are chartered, which is particularly true of the older institutions. It is a matter of very great difficulty to change that form of organization. As an illustration, in Minnesota there has been no acknowledged arrangement by which the alumni should have representation upon the Board of Regents, corresponding to the Trustees, although such representation seems to be very desirable. Only after several years of agitation was there success in getting one or two alumni members upon the Board of Regents, and that is done, not by right, but by courtesy. The matter was brought up at the psychological moment, before a properly disposed Governor, and he agreed to appoint two alumni upon the Board of Regents when a vacancy occurred. Since that time the succeeding Governors have been prevailed upon to appoint alumni as successors of alumni whose terms expire, and so we have an alumni representation upon the Board which has proven to be very satisfactory.

As to the official relations between the alumni and the university, it is difficult to make rigid statements which will apply everywhere. It seems to me the attitude that has been generally expressed here this afternoon is the correct one; that, generally speaking, the alumni organization should only have advisory power, and not have veto or appointive power. If the alumni are assured of representation upon the general governing Board of Trustees or Regents, then we may be sure that the alumni will be well represented in matters which they desire to bring to the notice of the Board of Trustees or the Board of Regents, and that these matters will be given proper attention.

M. C. Beebe: I am sure that all of the members of university faculties appreciate suggestions made by engineers in the field, in fact, we make every effort to get them to coöperate to as great an extent as is possible.

I cannot see any reason why a university, cannot be organized on the same sound principles which obtain in our best corporations. I think there is a chance for decided improvement, especially on the business side. The difficulties in the past have perhaps been due to the very rapid growth of the state universities, so that the development of the organization has tended to lag behind that of the growth of the institution itself but is not the same true of many business organizations?

I think we have got to go slow in applying the same standards of efficiency to the educational side that are applied to the purely manufacturing plant. The matter of economy should be judged

Digitized by Google

in a somewhat different way. True economy in education does not mean a low cost per student for there is no such competition to be met. Employers are not looking to our universities for cheaply educated men.

The only economy worth while and it is very well worth while is to turn out the best possible product with the money available for the purpose. This means among other things a careful selection and retention of good instructors and equipment.

Mr. Ford objected to the two-headed scheme, as he called it. It may be interesting to know that at the University of Wisconsin the two-headed arrangement is being tried out. We have the president of the university, and besides we have a newly appointed business manager, whose duty it is to look after all the purely business matters. He has under him the purchasing department, the Secretary of the Board of Regents, and Bursar and has control of the buildings and grounds.

The argument for this arrangement is that the institution is so large that it is impossible for one man to do justice to both interests, the pedagogical and business, and the work may better be divided. The situation is analagous to the case of a large corporation, where the various vice-presidents are given charge of separate divisions of the organization. Although this departure is somewhat new, it seems to be working very successfully.

W. L. Upson: There are many points in this paper which invite criticism. Some of these are already embodied in university organization and might be discussed from the standpoint of experience. In this respect may be mentioned what the author calls, "Schools and Departments of Instruction." This is proposed as a means of dividing the various college faculties into smaller and more workable bodies, and might be justifiable in an institution of 10,000 students. At present, however, these divisions are apt to be so totally devoid of power as to render them unnecessary and useless complications in the general scheme. In the college faculties, at present, important action is usually taken with departmental agreement and as departments are limited in number, the faculties are not as unwieldly as their actual membership might suggest. The author recognizes the value of alumni coöperation, and this can hardly be overestimated. Alumni representation on Trustee Boards has generally been productive of much good. His method of attacking the problem is novel, but will probably find few supporters. It appears like putting a horse-whip in the hands of an incompetent, but self-confident boy, who proceeds to make general havoc in stirring things up. It is doubtful if most state universities could command the services of 20 alumni who were capable of exercising such functions as are prescribed. Again, incompetency is not a general characteristic of university faculties. On the contrary, failure to obtain better results is rather due to insufficient means—too few and too poorly paid

Digitized by Google

instructors—and to lack of coöperation between faculty and trustees. These two bodies should be brought more closely together, not separated by another all-powerful body of doubtful competency. The interest of alumni should be secured by direct representation on the board of trustees.

A third criticism relates to the student advisory board. As proposed, this board is too small to be properly representative of the student body. It should, however, be recognized as a very important part of the university organization and be given as full and unlimited power over student activities as individual conditions would warrant.

Ralph D. Mershon (by letter): I regret exceedingly the circumstances which rendered it impossible for me to present this paper in person and take part in the oral discussion of it.

It is a matter of regret that no one outside the educational field took part in the discussion. The opinions of men who have had experience in large industrial organizations is most desirable in matters of this kind.

Mr. Ford's contribution is more definite and constructive than any of the rest of the discussion, and gives evidence of careful thought. There are some matters however on which I do not entirely agree with him.

He says that in my scheme "The fixing of authority is indefinite, particularly as to contentions between management and administration, with the result that frequently the Board of Trustees decides on matters of administration concerning which it has insufficient knowledge to act intelligently. The natural result is that the administrative officers are unable to maintain a definite policy, and consequently find it difficult to obtain the proper coöperation of those under them."

The fixing of authority should not be indefinite. My endeavor in drawing up the scheme was to definitely fix the authority; to give the President all the power requisite to make him fully responsible for the success of his administration, and yet not leave him so free from possible restraint as to invite the condition of czarism that has developed, and led to trouble, in some instances. For this reason, on further thought, I agree with Mr. Ford that the Secretary should not report directly to the Board of Trustees. For this reason, also, I prefer to make the Secretary, Registrar and Superintendent of Property report to the President directly, instead indirectly as Mr. Ford does. But there is no good reason that I can see why the Treasurer should report to the President. I would say, also, that if a "Board of Trustees decides on matters of administration concerning which it has insufficient knowledge to act intelligently," then, in my opinion, it is not a good Board of Trustees. A Board that properly does its work will call for such information as is necessary to enable it to act intelligently, and will see to it, in case of conflicting opinions, that information is had from authoritative sources on both sides of the question.

Digitized by Google

Mr. Ford, and others of those taking part in the discussion, think that there would be difficulty in having the Alumni Board advise the Board of Trustees and confirm appointments to the teaching staff. At Harvard, the Alumni Advisory Board, designated as the " Board of Overseers ", has, for many years done this very thing, and Dr. Eliot, in the Harris lectures on University Administration, sets forth this as one of the valuable and desirable functions of the Board. If such a scheme has worked successfully at Harvard, I see no reason why it should not in other universities.

My scheme contemplates an Alumni Advisory Board with the powers now had by the Harvard Board of Overseers. I recognize the fact that in instituting such an Alumni Advisory Board, in connection with a State University, it would be difficult, and perhaps inadvisable, to procure for them, officially, any such considerable measure of power as this. I believe, however, that an Alumni Advisory Board elected by the Alumni Association of a State University, under the restrictions as to membership provided by my scheme, that goes to work in a conscientious and careful way, will have all the power it needs in any direction in connection with the university, whether it has official recognition or not. I believe that in most state universities such a Board would be welcomed by the Executives and Trustees. That it is unlikely the Board of Trustees and the Alumni Advisory Board would ever come into conflict. But that if they ever should, and it should be deemed advisable by the Advisory Board to compel a course it recommended, it could do this by making a public statement of the matter at issue. I do not believe it would ever be either necessary or advisable to take such drastic action, but the power to take it would lie with the Advisory Board. The fact that the Board had this power would probably obviate the necessity for its ever being exercised; and the fact that such action would be drastic, would be a strong reason why the Board should be extremely cautious about ever resorting to it.

All the other suggestions made by Mr. Ford, insofar as they do not conflict with the exceptions above noted, seem to me eminently desirable and practical. I intend, so soon the leisure for it offers, to prepare a revised scheme embodying them.

Mr. Brackett asks: " Are the representatives of the Alumni likely to be any more expert in educational or technical lines than the average member of the Alumni Association." I believe the value of an Alumni Board will come through the fact that the members of it are not experts in education. Experts in any line are likely to become onesided and unable to take a common sense view of the relation of their work to the outside world. The very object of the Alumni Board is to have the benefit of the views of people not subject to educational myopia.

Some of those in educational work do not realize that an Alumni Board, made up of mature men who have had ten or

Digitized by Google

more years of worldly experience, is not going to interfere in matters unless it has good reason to do so. And that, generally, the individual members of it are in a much better position to acquire reliable information relative to any candidate for the instructional force than is anyone connected with the institution. The mere fact that an inquirer is connected with the institution makes it difficult for him to get information that is reliable.

Mr. Brackett also says that an Alumni Board with such influence may foster excessive inbreeding in the personnel of the faculty. Dr. Eliot's testimony is a sufficient answer to this. But I may say, from my own experience in connection with one State University, that the Alumni, generally, even those on the faculty, hold the view that there is too much inbreeding in most of the State Universities, and that it should be stopped.

Mr. Langsdorf says: "Where is the faculty? Its functions, which should be of the greatest importance in a democratic institution like a university, are apparently submerged and made subordinate to those of unduly exalted executives." I agree with Mr. Langsdorf that the functions of the faculty are of the greatest importance. The very object of the existence of a university is that the faculty may exercise its functions in teaching, but I do not believe that administration is a proper function of a faculty. I do not mean to say that the faculty and its opinions should be ignored in the administration. Quite the contrary. But I do mean to say that the average faculty member has not had that training which fits him to have a part in the administration of an institution and that if he had, the functions of instructing and administering do not properly go together.

Mr. Upson objects to the division of a college into schools and departments of instruction, saying that it might be justifiable in institutions of ten thousand students, but implying that it is not justifiable at the present time. It was an institution of ten thousand students, or more, that I had in mind in drawing up this scheme. The time will come, and is not very far away, when we shall have institutions of such size; and they will have to be handled. It seems to me we might begin now, nominally at least, to handle university work in this way, so that we shall be ready for the larger problem when it comes; to outline a skeleton organization which shall be conformed to now, as nearly as may be without needless duplication, and which can be put more and more nearly into effect as increasing numbers make it necessary. As our State universities become larger and larger the problem of handling them will become increasingly difficult unless there is now laid the foundation for such organization as will enable the proper handling of large numbers.

It has been found in manufacturing work, where one organization makes a great quantity and diversity of product, that the best results are gotten, not by having one great equipment to turn out the various products, but by having an institution

Digitized by Google

consisting of a combination of smaller institutions, each with its own equipment, and each turning out its own line of product. It is by such course, only, that the individual product can receive anything like the individual attention it must receive for best results. And under such an arrangement the product can be turned out of better quality and with less waste of time and money, even though it involves a duplication of equipment. It seems to me this applies to educational institutions, and that eventually we must have in all universities separate and distinct colleges involving more or less duplication of instructive force and equipment, in order that we may turn out the best product; in order that the product shall receive the same individual attention it does in smaller institutions. By such a course we shall retain all the advantages of the large institution while doing away with the disadvantage that the large institution is now considered to have as compared with the smaller one; and at the same time establish lines of growth along which the institution may continually and naturally expand to meet the requirements of continually increasing numbers of students and the demands for additional courses of instruction.

Digitized by Google

DISCUSSION ON "ELECTRIC STRENGTH OF AIR II," "THE LAW OF CORONA AND DIELECTRIC STRENGTH OF AIR." CHICAGO, JUNE 29, 1911. (SEE PROCEEDINGS FOR JUNE AND JULY, 1911.)

(Subject to final revision for the Transactions.)

C. P. Steinmetz: The papers of Dr. Whitehead and Mr. Peek, Jr. are of momentous importance by solving the problem, which threatened to stop the further advance of high voltage power transmission. the corona or loss of power by discharge into the air. From an unknown danger, corona thus becomes a phenomenon amenable to exact calculation and predetermination.

Mr. Peek's paper, while very voluminous, is only a short abstract of some of the more important results of an investigation, which is probably one of the most extensive experimental electrical engineering investigations ever undertaken.

Some of its results are:

The loss of power by corona is proportional to the frequency and to the square of the excess voltage above a certain critical voltage, the disruptive critical voltage.

This disruptive critical voltage is that voltage, at which at the conductor surface a certain definite and constant potential gradient is reached, which is 30 kv. per centimeter, independent of size of wires and distance, but is proportional to the air density, that is, the barometric pressure and the absolute temperature, and may be considered as the dielectric strength of air.

The corona, involving luminosity and conductivity of the air and loss of power, does not yet begin, when the dielectric strength of air, that is, the disruptive voltage gradient, has been reached at the conductor surface, but only after the disruptive gradient has extended a finite distance from the conductor, that is, after an envelope of dielectrically over-strained air of a finite thickness has been formed around the conductor, and a definite amount of energy has become available thereby. In this respect, corona formation is analogous to other phenomena of gas conduction, as the electric arc, which latter also requires a definite amount of energy for its starting.

There are thus two definite critical points: the disruptive critical voltage, e_0, at which the disruptive critical gradient, that is, the dielectric strength of air, of 30 kv. per cm., is reached at the conductor surface, and the visual critical voltage e_v, at which the disruptive critical gradient has spread from the conductor to a sufficient distance to give the energy of corona formation, and luminosity and power loss begins. At the latter voltage, the gradient at the conductor surface is higher than the disruptive critical gradient, the more so, the smaller the conductor diameter, and the ratio between the visual and the disruptive voltage respectively gradient is given by equation (1) of Dr. Whitehead's paper, which is not only in its form, but even in its numerical constants the same as the corresponding equation of Mr. Peek's paper.

Digitized by Google

The theoretical loss curve, that is, that of a conductor of perfect surface, would then have the shape as shown in Fig. 1, that is, start abruptly with a finite value at e_v, while the dotted part from e_0 to e_v is unstable, just as in the arc characteristic a similar discontinuity occurs at the intersection with the "stability curve."

Another interesting result of Mr. Peek's paper is, that the lower part of the numerous previously published corona loss curves, which has been variously expressed as "sub-corona," or "part corona" etc., is nothing but the effect of the irregularity of the conductor surface, and as such follows the probability law.

Humidity of the air is by Peek's paper finally eliminated as one of the factors which might have an effect on corona. So also is the free ionization of the air. A pronounced effect however is produced by any solid or liquid contained in the air, as

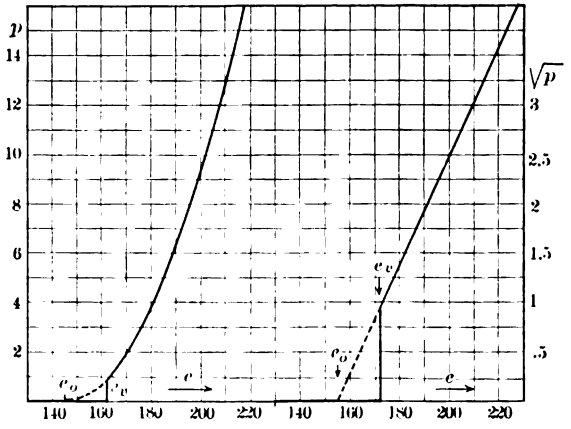


FIG. 1

smoke, rain, snow, sleet, etc., and the effect is a great increase of loss and decrease of the voltage where the loss begins.

Dr. Whitehead's paper specifically deals with the quantity, which in Peek's paper is called the "visual critical voltage e_v" and the "visual critical gradient g_v," the values of voltage, at which corona begins, that is, at which, according to Peek, the disruptive strength of air has been exceeded for a sufficient distance from the conductor, to supply the energy required to start the luminous discharge or corona.

There are some apparent discrepancies between the results of Dr. Whitehead and those of Peek: Peek shows that the disruptive critical voltage, the dielectric strength of air, and the constants of the corona equation are independent of the frequency, while Dr. Whitehead shows that the visual critical voltage slightly decreases with the frequency. Peek shows that the

Digitized by Google

dielectric strength of air is proportional to the density, while Whitehead, extending his observations over a wide range of pressure, shows the visual critical voltage to vary less than proportional to the air density. However, these discrepancies are only apparent, as Peek refers to the disruptive critical voltage e_0, Whitehead to the visual critical voltage e_v, and the effect observed by Whitehead should rationally be expected from Peek's results: Peek shows the disruptive critical gradient g_0 to be proportional to the air density, but corona to begin when the disruptive gradient has extended a finite distance from the conductor, that is, after the formation of an envelope which supplies the energy of disruption. At this point, at the conductor surface a higher gradient g_v has been reached. At lower air densities, the energy of the dielectric field is less, and it should therefore be expected, that a greater thickness of envelope would be required to supply the energy of disruption, that is, the visual gradient g_v should vary less than proportional to the air density. Similarly, at higher frequency and thus greater flow of power into the dielectric field of the conductor, less thickness of the envelope of overstrained air would be required to give the energy of corona formation, and increase of frequency thus should have the effect to decrease the visual critical voltage e_v, at constant disruptive critical voltage e_0. That is, in Peek's equation relating the visual gradient g_v and the disruptive gradient g_0

$$\frac{g_v}{g_0} = 1 + \frac{0.301}{\sqrt{r}}$$

(which is equation (1) of Whitehead's paper).

The constant 0.301 should contain the air density δ and the frequency f as terms.

This is a field for further investigations.

In conclusion, I wish to congratulate Dr. Whitehead, not only on the valuable results of his paper, but more still on the form in which the results are given, as empirical facts without coloration by the terminology of any metaphysical speculation, as unfortunately is done so often today, but the speculative interpretation is separated from the statements of the facts. However, from the view point of the ionic theory—in which I do not believe—the facts of Peek and Whitehead's paper appear easy of interpretation.

The dielectric strength of air or disruptive critical gradient is that field intensity, which during the main free path of an ion gives it a velocity sufficient to produce ions by collision. The dielectric strength of air thus must be a constant, independent of the size and distance of the terminals. The corona then is the result of ionization by collision, and the density of the ions in the corona is enormously high compared with the highest natural ionization of air. Starting then from the few free ions

Digitized by Google

existing near the conductor, in the formation of corona these ions accelerate by the dielectric field to form new ions by collision, these again accelerate to collision velocity, and in this manner by successive collisions of the free ions formed by collision gradually the ionic density increases to the value required to give conductivity and luminosity, that is, corona. As a very large number of successive collisions are required to increase the ionic density to that in the corona, it follows, that the ionization density of the dielectric field must extend over a distance from the conductor, which is very large compared with the free path of the ion, that is, an envelope of finite thickness of over-strained air is required for corona formation, as brought out by the facts of Peek's paper. Or, from the energy point of view, a finite amount of energy is required for corona formation: the $\sum \frac{m v^2}{2}$ of all the ions which have been accelerated to collision velocity, until corona density of ions is reached.

At lower air densities, the free path of the ions is longer and the field intensity required to produce collision velocity, that is, the disruptive critical gradient, or dielectric strength of air, proportionally lower. However, at the longer free path, a greater thickness of the envelope of over-strained air is required to increase the ionic density by successive collisions to that required by the corona, and thus the visual critical gradient must vary less than proportional to the air density, in agreement with the results of Whitehead's paper, while the disruptive critical gradient should be directly proportional to the air density, as given by Peek's paper.

The free ionization of the air can have no effect on the critical alternating voltage, where corona begins, nor on the power loss, since at every half wave of alternating voltage the corona formation starts not with the free ionization of the air, but with the residual ionization of the preceding half wave, which, while extremely small compared with the ionic density in the corona, is large compared with the free ionization of the air. This residual ionization however should to some extent vary with the frequency, and at higher frequency be higher, thus requiring a lesser thickness of the ionizing envelope, that is, a lower visual critical voltage e_0, in accordance with Whitehead's paper. Following an exponential function, the ionic density at the formation of the corona, and at its disappearance should pass through the critical corona value very abruptly, that is, the point where corona forms, and where it disappears, should be the same and very sharply defined, as in agreement with empirical evidence.

While the free ionization of the air can have no effect on alternating corona, it should have an effect on corona formation by a single voltage impulse of very short duration, and such a very short transient voltage should either give no corona at all—if its duration is less than the time required to reach corona density

Digitized by Google

by successive collisions—or only at a very much higher, and more or less indefinite voltage. That is, a much greater thickness of ionizing envelope should be required to reach corona ionization from the low natural ionization of the air, than from the higher residual ionization of the alternating corona. With alternating corona, this should give a corona transient probably extending over several half waves. Experience seems to point to the absence, or the much lesser extent of corona with transient voltages, than with alternating voltages. Thus for instance insulators, designed to flash around much below their puncturing voltage, frequently puncture with transient voltages of short duration, as lightning, without flashing over. That is, with an alternating impressed voltage, corona spreads over the insulator until followed by a disruptive discharge over the surface, long before the disruptive strength of the insulator material is reached. At a short transient voltage however, none or very little corona seems to form, and the flash-over voltage thus becomes much higher, and above the puncture voltage. However, this entire field of corona formation with transient voltages, though of high industrial importance, is still practically unknown and work in its exploration is contemplated.

Cassius M. Davis: During the investigations made to determine the relation between the visual corona voltage, the diameter of the conductors and the distances between them, the observations were carried down to very small distances of separation, even below the point where corona ceases to form and disruptive discharge takes place, and some rather interesting results were obtained.

Where voltage is applied to two parallel wires or conductors the distribution of potential between the conductors is not uniform, but the potential gradient is greater at the conductor surface than at any other point. If the applied voltage is high enough the air immediately surrounding the wires becomes conducting and luminous as far as the potential gradient exceeds the dielectric strength of air. Since the medium surrounding the wires is now conducting the real surface is no longer the metallic surface of the wire but some surface distant from it by the depth of the conducting envelope about it. The boundary of the corona is determined not by the equipotential surfaces surrounding the conductor, but by the equigradient surfaces. These curves are not concentric with the metallic conductors but are nearer together.

The general mechanism of corona formation may be described as follows: Upon the gradual increase of the applied voltage a value is reached which gives, at the conductor surface, a potential gradient sufficient to break down the air. In this way the air becomes conducting as far from the conductor as the gradient exceeds the breakdown value. This decreases the distance between the conductors, but increases their diameter. The former tends to increase, the latter to decrease the gradient

Digitized by Google

at the surface of the effective conductor. If then the distance between the wires is large compared with their diameter, the decrease of gradient due to the increasing conductor diameter is greater than the increase due to their decreasing distance, since the decrease of distance is a relatively small part of the total distance between wires. At the outside of the effective conductor, that is, outside of the space filled by the conducting air or corona, the gradient is less than it would be at the surface of the wires, and the discharge between wires thus limits itself to a corona extending as a more or less uniform glow, up to the distance at which the potential gradient is the breakdown gradient. If, however, the distance between the conductors is so small that the increase of potential gradient due to the decrease of distance between the effective conductors, resulting from the corona formation, would be greater than the decrease

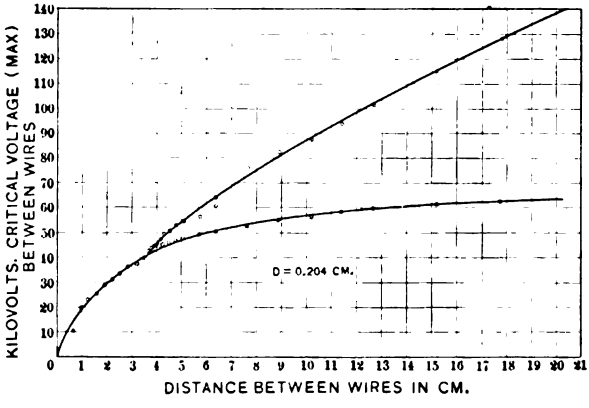


FIG. 1

due to the increasing conductor diameter, corona cannot form, but as soon as the discharge into the air begins at the conductor surface, it increases the potential gradient and thereby passes across between conductors as a disruptive discharge. Thus if the conducting envelope produces a decrease of the potential gradient between the wires, corona appears; if it produces an increase, disruptive discharge takes place.

The transition from disruptive discharge to corona is rather interesting to observe. Starting with the conductors very close together and gradually separating them, maintaining the potential at the critical value all the while, a point is reached where the disruptive discharges become less sharply defined and less snappy; and intermittently between the more noisy discharges are very quiet and, what may be called, puff discharges. These are intermediate in intensity between the disruptive and corona

Digitized by Google

discharges. If the distance is further increased a point will be found where corona begins, and by carefully adjusting the distance a position can be determined where, at the same applied potential difference, all three discharges take place one after another in various orders of succession. This shows very nicely that corona, like the Geissler tube discharge, is a form of disruptive discharge.

If the wires are separated by a greater amount than this critical distance and corona is produced at the critical voltage, a disruptive discharge may again be brought about by raising the voltage above the critical value of corona formation. Thus if a curve is plotted between voltage or potential gradient and separation between conductors it consists of a single line up to the critical distance then at that point it divides forming two branches, one for disruptive discharge and one for corona. Two

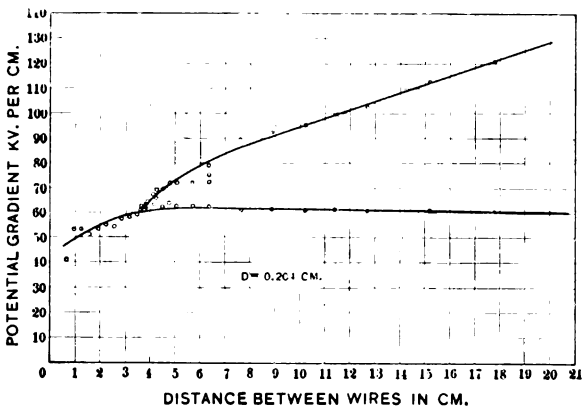


FIG. 2

such curves, one showing the voltage, the other the potential gradient at the conductor surface are given in Figs. 1 and 2.

The critical distance where corona begins increases with increasing diameter and should probably be of such a value as to give a constant ratio between the separation distance and the diameter. It is rather difficult to calculate this ratio because of the complex shape of the equigradient surfaces. Based on cylinders whose sections are circles concentric with the metallic conductor, the ratio is about 3.3; and based on cylinders whose sections are eccentric circles with constant distance between the outside surfaces, the ratio is about 4.1. Experimentally this ratio seems to be about 25, indicating that the precise shape of the equigradient surfaces should be determined and used in the calculation. The accompanying table gives the experimental values of the diameter, critical distance, critical potential dif-

Digitized by Google

ference to neutral in kilovolts, gradient at the surface and ratio of critical distance to diameter.

Diameter cm.	Critical distance cm.	Visual critical potential	Potential gradient at surface	Ratio $\frac{\text{Critical distance}}{\text{diameter}}$
0.0344	1.8	7.6	96.4	52.3
0.0780	2.7	13.0	81.1	34.6
0.1662	3.6	19.7	66.4	21.6
0.204	3.6	20.7	60.6	17.6
0.320	7.8	35.0	58.6	24.4
0.513	13.3	49.1	50.2	25.1

No great accuracy is claimed for these results, since the apparatus used in the experiments was designed to be employed for comparatively great distances, and small distances were difficult to measure accurately; however they serve to show the general magnitude of the values.

The disruptive branches beyond the critical distance (giving the relation between voltage and size of conductors) approach each other, and beyond separation distances of 10 cm. have practically the same values for wire diameters within the range used in the tests. The lower end of the disruptive branch, that is, the part below the critical distance, seems to point toward approximately the value 30 kv., at zero distance, determining the dielectric strength of air in another way. This is reasonable because the surfaces when very close together become planes and the distance between them becomes less than the thickness of any envelope of conducting air around them, and thus the gradient at the surface of the conductor becomes the breakdown gradient of air.

The accuracy with which the critical voltage can be determined visually is quite remarkable. Observations can be made with very little practice which check within one per cent of each other. This applies as well for laboratory measurements as for determinations made upon an actual transmission line. The visual method has the advantage over other methods in that the effect of point discharges can be eliminated since a portion of the conductor can be selected for observations which is free from irregularities. That the visual point is the point where ionization begins is very nicely illustrated in the papers by Messrs. Whitehead and Peek, in which, working independently each derives almost the identical equation for critical voltage: one using the ionization point, the other the visual point; one using a conductor concentrically located in a cylinder, the other two parallel wires.

The appearance of corona is greatly dependent upon the surface condition of the conductor. A perfectly smooth and polished copper wire exhibits corona as a very soft uniform

Digitized by Google

glow; however if the discharge is allowed to continue a short time the glow becomes less homogeneous and soon appears in tufts with the space between almost non-luminous, giving the wire the appearance of a string of bright beads. An examination of the conductor after this " beading " has continued a while shows alternate stripes of the bright wire and dull oxide which latter rubs off easily as a black substance.

The mass of information now available upon the subject of corona formation on transmission lines is quite voluminous, and high potential lines can be designed with considerable accuracy with regard to the amount of energy dissipated into the air; also the critical voltages can be calculated very accurately and avoided. With other apparatus conditions are different, and while the critical voltage can be estimated very closely, and in a measure avoided, yet with insulation other than air, which is hardly ever homogeneous, and very limited distances of separation, the means of eliminating corona and its accompanying deleterious effects are less understood and a very large field is offered for investigation.

A. B. Hendricks, Jr.: One of the most striking features of the papers of Whitehead and Peek is the great accuracy of the results reported, especially in the determination of the voltage required to produce visual and audible corona. This at once suggests the possibility of constructing a corona voltmeter as proposed by Professor Ryan and others—and its use for high tension measurements in place of the needle point spark gap. Such an instrument could be made to give both visible and audible indications with a probable accuracy of one-half per cent.

The form and arrangement of electrodes should of course be such as to produce corona at a voltage far below the arcing voltage, thus avoiding short circuits and high frequency oscillations in the high potential system. This feature, together with the reliability of the indications, would render the device very valuable for high tension investigations and much superior to the needle point spark gap.

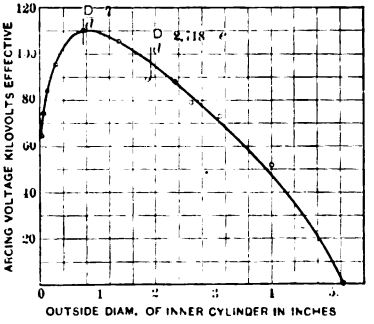
The accuracy of Whitehead and Peek's measurements also demonstrates the usefulness of the voltmeter coil on the high tension transformer core, as nearly all of the determinations were made by this means, though checked by independent methods. This method has met with some criticism on the score of alleged inaccuracy, therefore the results are very gratifying and furnish sufficient proof of reliability.

Theory seems to indicate that the dielectric strength of the air between concentric cylinders is a maximum for a ratio of cylinder diameters equal to 2.718 or the base of the natural logarithms. Experiment shows that this is not the case but that the actual ratio is very much greater. For example—with a diameter of $5\frac{1}{4}$ in. for the outer cylinder, the maximum was reached with an inner cylinder one-eighth inch in diameter, whereas theory indicates that this should be one and five-eighths

Digitized by Google

inches. The most definite results, I have obtained illustrating this point, are on transformer oil and are best shown by the accompanying curve Fig. 1. In this case, the ratio of diameters for maximum dielectric strength was found equal to seven. Possibly from their own investigations, the authors may be able to give an explanation of the cause of this discrepancy. At any rate, the fact seems to be established and should be taken into account in high tension design.

Another interesting phenomenon though not directly connected with the subject of these papers, is the effect of pressure on the dielectric strength of oil. I have investigated this point but slightly and find that the dielectric strength is increased about 50 per cent by a rise in gauge pressure from zero to 200 lb. per square inch. Presumably others have more complete information regarding this effect, and, if so, it is suggested that their results would be of great value and interest if presented to this Society. This property of oil may render possible the construction of apparatus for extreme high tensions, normally operating under high oil pressure.



D = inside diameter of outer cylinder = 5.25 in. constant
d = outside diameter of inner cylinder = 0 005 − 4.56 in

FIG. 1.—Arcing voltage between concentric cylinders under oil

Charles F. Scott: I will not attempt to contribute to the technical discussion of the subject. The former speakers have dwelt upon these technical points and given a most excellent discussion. I would like, for a moment, however, to take a general survey, to show the progress we are making in transmission.

It is not so very many years since 40,000 volts marked the high range of potential of operating pressure. A paper before the Institute a dozen or thirteen years ago, describing Mr. Mershon's work at Telluride gives tests which were limited to two and a half or three miles in length, in which the voltages used were in the main from 50,000 to 70,000, although a few tests ran up to 110,000 volts, which I believe was the limit of insulation of the transformer, as demonstrated by the test itself, with inadequate instruments and methods devised by Mr. Mershon on the ground under the greatest difficulties—those were the conditions only a few years ago.

A few years later, in the static investigations to which the Chairman referred, which were made by Mr. Thomas himself, the potential was as high as seventy thousand volts, and the tests were made on a number of commercial lines in the West.

Digitized by Google

Now, we have tests covering three hundred miles of line, for normal operation, at 100,000 volts, and we have a fundamental knowledge of the phenomena on which to base the tests, which are made with instruments which were not in existence until a few years ago. The oscillograph has opened up and given us photographs of just what is going on which made possible a new order of investigation and enlightenment.

A word should be said as to the amount of time, labor and money which must be expended on tests of this kind; also commendation should be made of the excellent policy of presenting so freely and fully these measurements before the Institute, not only with the results obtained on lines in the west, but those on the experimental lines at Schenectady. The general result of all these investigations has been most valuable. All papers of this morning have contributed to our knowledge of the conditions in the high voltage field, and have not busied themselves in bringing up impediments and difficulties, but they have defined the conditions of operation, and have been extending the possibilities and the certainties of high tension transmission by showing definitely what those conditions are. Sometimes papers deal with the discovery of some phenomena which are impediments, some times papers deal with special devices for overcoming special difficulties, but here we have a larger scientific investigation, showing what the conditions are, and fortunately, if I am not mistaken, not bringing up new hindrances, but blazing the way for the extended commercial development of high tension transmission and making its operation more sure.

Harris J. Ryan: Dr. Whitehead has evolved out of the original crude concentric cylinders outfit for the laboratory study of corona an instrument of precision that offers a wide range of application in the exact study of the essentials of corona phenomena. In the concentric cylinders method the atmosphere between the cylinders is stressed in a balanced electric field. When the surface of the central cylinder is true and free from all foreign material, ideal conditions exist and the turbulent elements that enter into the practical case giving rise to the "irregularity factor" are absent. Dr. Whitehead's studies are therefore, particularly valuable because his results constitute a foundation or base upon which to rest judgment of the conditions and relations that exist in the practical cases as they arise. He has found that the electric surface-intensities which start to cover a clean cylindrical conductor with visible corona in a balanced electric field are

$$E_1 = E_0 = 32 + \frac{13.4}{\sqrt{d}},$$

while Mr. Peek has found that these same corresponding electric intensities which start to cover a clean cylindrical conductor

Digitized by Google

in the unbalanced field set up between two equal parallel cylinders are

$$E_1 = 29.8\left(1+\frac{0.301}{\sqrt{r}}\right) = 29.8+\frac{12.7}{\sqrt{d}}$$

The ratios of these corresponding values are nearly constant for all diameters likely to be employed in engineering as may be seen in the table below:

d cms.	E_0 kv/cm.	E_1 kv/cm.	E_1/E_0
0.2	61.95	58.17	0.939
2.0	41.47	38.77	0.935
6.0	37.46	34.98	0.934

When these formulas are applied to the case of parallel plate electrodes, $\sqrt{d}=\infty$, and the values of E_0 and E_1 are the corresponding ultimate dielectric strengths of the normal atmosphere stressed by a uniform electric field:

$E_0 = 32$ kilovolts per centimeter.

$E_1 = 29.8$ kilovolts per centimeter.

There should be no question about the integrity of each of these values. Their ratio is

$$\frac{E_0}{E_1}=\frac{32}{29.8}=.93$$

For some time physicists have concluded through methods peculiar to their studies of the conduction of electricity through gases that the dielectric strength against rupture of the normal atmosphere using unbalanced electric fields in the open is quite close to 30 kv. per cm. Mr. Peek's value of 29.8 found by totally different methods is quite in agreement therewith. Dr. Whitehead's value of 32 applies to the normal atmosphere enclosed and stressed in a balanced electric field. It applies, therefore, to conditions in which all irregularity effects are quite completely eliminated. Therefore, one may safely use 32 kv. per cm. for the ultimate dielectric strength of the normal atmosphere in constructing a rational formula for the critical visual corona voltage provided they include the factor 0.93, due to the change in the electric fields from one that is enclosed and balanced to one that is in the open and unbalanced, *i.e.*, as set up between two equal parallel cylinders.

In the present papers we have placed before us conclusive evidence that corona starts to cover a round conductor in the open when the normal air is stressed to 30 kv. per cm. at a distance of $a = 0.301\sqrt{r}$ cm. radially from the conductor surface.

Digitized by Google

The theory of ionization by collision which accounts for this phenomenon insists that the normal rupturing strength, 30 kv. per cm., must be directly proportional to the atmospheric density factor

$$\delta = \frac{3.92\,b}{273+t}$$

and to $0.301\sqrt{r}\,f(\delta)$. There is substantial evidence* that $f(\delta)$ in $0.301\sqrt{r}\,f(\delta)$ is so nearly constant and so near unity over the whole range of natural atmospheric variations observed by barometer and thermometer that it is entirely safe to use $f(\delta)=1$ in $a=0.301\sqrt{r}\,f(\delta)$. Thus beyond all doubt so far as theoretical reasoning can settle such matters the barometer-thermometer correction factor in the rational visual corona critical voltage formula must be

$$\delta = \frac{3.92\,b}{273+t}$$

Dr. Whitehead has again undertaken to show that I am wrong in regard to the effect of electrified atmosphere upon the visual corona critical voltage; he does this by proving what I have all along stoutly maintained, *viz.*, that no amount of electrification will alter the critical voltage as observed in his apparatus. The theory of ionization by collision that applies here necessarily makes this so. In the open atmosphere about parallel cylinders which never remain " clean " and with their unbalanced electric field it is a different matter. The " coreing up " phenomenon comes in and electrification or " antecedent ionization " introduces part-corona or local-corona which starts at lower surface gradients and therefore at lower critical voltages. He also renews his objection to the experiment referred to in Fig. 28 of my January 13, 1911 paper. My reply to such objection appears in the corona discussion published in the PROCEEDINGS of May, 1911. He offers also the conjecture that some of the surface intensities reported in my paper are erratic as to position because of lack of care as to high-voltage wave forms employed and in making the visual settings for the initial corona. I do not think this is so. I refer to this matter later on so as to reply to the question here raised.

Regarding Mershon's work at Niagara Falls referred to several times in the present corona papers: Anyone who repeats Mershon's observations at the same point as to location and under the same circumstances as to wind and weather should find just about the same values that he found. In doing this the be-

*PROCEEDINGS A. I. E. E., January, 1911, curves I and III Fig. 4, p. 6; also, compare the Townsend values Fig. 15*b*, p. 21 and the *B-PS*-values of Fig. 6, p. 8 of the same paper.

Digitized by Google

havior of the high-voltage circuit with ungrounded neutral must be kept in mind as well as the importance of the electrification of the atmosphere produced by the falls in connection with conductors having surfaces in various physical states.

All who are interested in the corona problem will find Mr. Peek's paper a mine of valuable results, well produced and applied. His work has decided a number of things about which uncertainties have heretofore existed. He shows conclusively that:

1. The dielectric strength of the normal atmosphere at rupture is very close to 30 kv. per cm. This is in agreement with the corresponding value found by the physicists who have employed entirely different methods.

2. Corona will form and cover the surface of a clean conductor in the normal air whenever the potential of the conductor is raised to the value whereat the air is stressed to the breaking point, 30 kv. per cm., at a *critical distance* normal to the conductor surface, thus vindicating the conclusions drawn from the results of Steinmetz and Hayden by the energy-storage method, of Townsend through his established theory of ionization by collision and of Baille-Paschen-Schuster by the critical sparking distances between metal spheres.

3. The initial corona forming voltage is proportional to the density of the atmosphere.

4. An *irregularity factor* must be applied in the rational formula for the initial corona voltage in the practical case because of turbulent elements that are not subject to systematic coördination. Judgment with a knowledge of the conditions must be employed to determine the value of such irregularity factor.

In addition hereto the paper gives the law governing the loss of power in corona about a high-tension transmission line as the voltage is elevated from the corona starting value. This is likewise of much importance. It will help the engineer to know in advance how much power will be lost by corona in a high-tension transmission that must in emergencies or otherwise be operated at a voltage above that which inaugurates corona. It is altogether possible too that high-tension transmission lines may be operated at critical corona voltage over strategic sections or over branches, loaded or unloaded, as an aid to or as a substitute for the static arrester. Should such practice come about this corona power law will become invaluable in connection therewith.

Mr. Peek has found that the critical radial distance from the cylindrical conductor surface through the initial corona envelope is such as to make the radius of the outer surface of the envelope

$$r_v = r\left(1+\frac{0.301}{\sqrt{r}}\right) = r+0.301\sqrt{r}$$

wherein r_v, is the radius of such corona envelope;
r, is the radius of the conductor.

Digitized by Google

It is a great satisfaction to find that the thickness of the initial corona envelope is a simple function of the radius of the conductor because the rational derivation of the initial corona forming voltage formula must include this thickness. There can be no question about the integrity of this result, applicable to engineering sizes. There are at hand three independent checks as follows:

Dr. Whitehead's corona starting surface-intensities are given by the expression

$$E = g_v = 32 + \frac{13.4}{\sqrt{d}}$$

Which may be written in the form

$$g_v = 32 \quad r + 0.296 \sqrt{r}$$
$$r$$

$$a = 0.296 \sqrt{r}$$

Wherein a is the corona striking distance or thickness of the initial corona envelope corresponding to Mr. Peek's value

$$a = 0.301 \sqrt{r}$$

The critical striking distances between metal spheres in the normal atmosphere observed by continuous voltage many years ago* give an average of

$$a = 0.300 \sqrt{r}$$

Mr. Peek's method for evaluating a has been applied to the surface-intensity values observed some years ago by the concentric cylinders visual method.† (See accompanying diagram Fig. 1.) The resulting value of the initial corona thickness is

$$a = 0.316 \sqrt{r}$$

These are all in remarkable agreement, considering the circumstances. Less confidence is placed in the last value than in the others. It is higher by five per cent due more likely to the character of the surfaces of the conductors used than to errors in observation. All settings were repeated several times; waveforms were watched by means of a special oscillograph connected in series with the high tension test circuit, also in series with an air condenser across such circuit, besides the maximums of all high voltage waves were carefully checked with needle

*PROCEEDINGS A. I. E. E., January, 1911, Vol. XXX, p. 8.
†TRANSACTIONS A. I. E. E., Vol. XXIII, p. 101, 1904.

Digitized by Google

point spark gaps. It is not thought that these 1904 values are erratic so much through errors of observation as suggested by Dr. Whitehead in his present paper. The cause is probably the condition of the surfaces of the brass rods used for all sizes above 0.2 inch. While clean in the ordinary sense they were not "clean" as the present day corona term implies. It is a happy event to have this corona feature cleared up so well by Mr. Peek. It establishes the integrity for the rational formula for the visual critical corona voltage which is written by him thus:

$$e_r = 2.302\ m_v\ g_0\ \delta\ r\ \left(1+\frac{0.189}{\sqrt{r}}\right)\ \log_{10}\frac{s}{r} \quad \text{.....[(5a) p. 1495]}$$

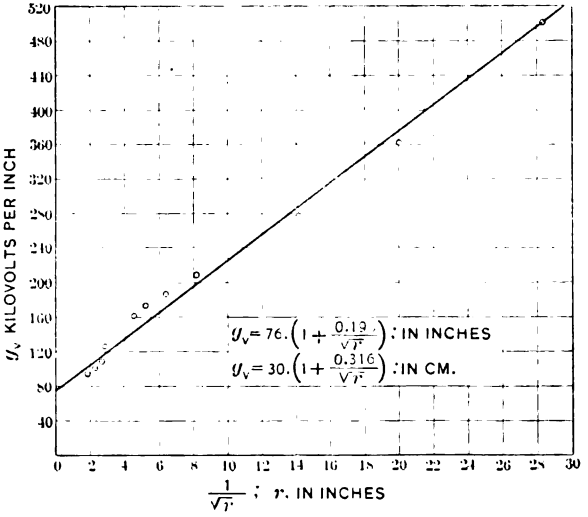


FIG. 1

and as given in the January 1911 corona paper thus:

$$E_{crit} = 0.455\ k\ \frac{17.9\,b}{459+t}\ \frac{d+2\,a}{C} \quad \text{.....[(3) p. 69]}$$

wherein E_{crit} = critical loss in kilovolts, effective sine-wave. (This is the same as visual critical voltage.)

k = factor selected by judgment guided by the results of practical tests and experience.

d = outer diameter of wires or cables in inches.

a = corona striking distance in inches obtained from curve in Fig. 2, January, 1911, PROCEEDINGS A. I. E. E., p. 4

b = barometer, inches of mercury

t temperature, degs. fahr.

C capacity of the line in microfarads per 1000 feet.

Digitized by Google

This applies to the single phase line. For the three-phase line, E_{crit} and C are taken to neutral.

Substituting Mr. Peek's function for the conductor radius, $0.301\sqrt{r}$, for the corona striking distance or thickness of the initial corona envelope (a) the above formula (3, p. 69) becomes in English measure

$$E_{crit}=0.455\ k\ \frac{17.9\,b}{459+t}\ \frac{d+0.267\sqrt{d}}{C} \quad \ldots\ldots\ldots \quad (3a)$$

Or in Mr. Peek's notation:

$$e_g=0.455\ m_v\ \delta\ \frac{d+0.267\sqrt{d}}{C}$$

This is a somewhat more convenient form of the rational formula for use. One can take the values of C from the usual capacity tables in lieu of having to work out $\log s/r$. This formula has now been checked for all conductor sizes varying from diameters of 0.005 to 0.5 of an inch, while there is good laboratory evidence through the critical surface intensities and striking distances found with spherical electrodes that the formula will be correct for all conductor diameters below 2.5 in.

It is a matter, for the present at least, more of theoretical than of practical interest, that $a=0.189\sqrt{r}$, does not hold for diameters much above 2.5 in. Where $r=\infty$, *i.e.*, with plate electrodes this value for a becomes ∞, while under these circumstances the critical surface-intensity occurs at a striking distance already known to be

$$a=0.268 \text{ inch.}$$

Available evidence shows that the value of a as a function of the conductor radius or rather of the diameter d between the limits of $d=0.25$ in. and $d=\infty$ will be found to be quite close to

$$2\,a=\frac{d}{1.4+1.86\,d}$$

$$2\,d=\frac{1}{\frac{1.4}{d}+1.86}$$

When $d=\infty$

$$a=0.268 \text{ inch.}$$

Digitized by Google

The corresponding rational formula for the critical visual corona voltage would be

$$e_v = 0.455\, m_v\, \delta \left(1 + \frac{1}{1.4 + 1.86\, d}\right) \frac{d}{C}$$

This formula is in close agreement with Mr. Peek's corresponding formula for all diameters from 0.25 to 2.5 in. while it is probably quite correct for all larger diameters. As just stated, it is perhaps more of theoretical than of practical interest. However, it is in further support of the integrity of Mr. Peek's values, $a = 0.189\sqrt{r}$, because the relation

$$2a = \frac{d}{1.4 + 1.86\, d}$$

is known to be true for the largest diameter, $d = \infty$, and at the same time covers his values between the limits $d = 0.25$ and $d = 2.5$ in.

The critical striking distance a is now known, therefore, quite exactly between the limits of $d = 0.005$ and $d = 0.5$ in. and its function of the conductor diameter for all larger sizes is probably known within five per cent of the true values.

Mr. Peek's conclusions in regard to the values of the irregularity factor are important, based as they are on such extensive outdoor line tests. They are further supported by a considerable number of less comprehensive tests reported in the present PROCEEDINGS.* His formula (3) and (5) for "disruptive critical voltage" are rational in their derivation and their constants are now all known with fair exactness; exception is made for the irregularity factor (m_v), which in the nature of things must, in part at least, be settled by judgment. The facts brought out in this paper are a great help to decide upon the value of this factor in most actual cases as they arise. In due course of time doubtless, more data will be brought forward to help one to decide upon this factor under the most trying or extraordinary conditions. These formulae (3) and (5) will hereafter be a reliable guide to the high-tension engineer in designing transmission lines so that waste of power in corona will be avoided.

The high-voltage measurements here reported upon were made on circuits operated with the neutral grounded. This should always be the case when definite results are to be obtained. Initial corona values on a completely insulated high-voltage circuit in the open will vary somewhat because the absolute potential of the line, under these circumstances, will vary due to the electrification of the atmosphere. Unless the purpose is

*PROCEEDINGS A. I. E. E., Vol. XXX, p. 70, January, 1911.

Digitized by Google

to watch the varying effects upon initial corona values due to the electrification of the atmosphere surrounding a completely insulated high-tension circuit such circuit should be grounded at the neutral.

John B. Whitehead: Before replying to the discussion of my own paper I shall comment briefly on that of Mr. Peek. The Institute is to be congratulated on the mass of data which it contains and on the liberal spirit of the company he represents not only in conducting the experiments, but in offering the results to the profession. Such experiments on a scale approaching the conditions of practice, paralleled by accurate laboratory investigations will quickly settle the uncertainties of this great corona problem or indeed of any other of the many constantly before us in the applications of electricity. It is a great pleasure to find that where the work of Mr. Peek has coincided in sphere with my own, the results are in such good agreement.

The title of my paper is the "Electric Strength of Air." The word *electric* indicates that the air is considered as regards its behavior under electric intensity or strain. The word "*dielectric*" by its origin and long usage refers to the inductive property of a substance, which property has no definite relation to its disruptive strength. The term "dielectric strength" therefore suggests the specific inductive capacity or perhaps some limit of specific inductive capacity. The term as adopted by Mr. Peek to describe the disruptive strength has been used rather commonly in this country, but the origin and present sense of the word *dielectric* would seem to indicate that its use in this connection is a mistaken one.

A further question of terminology is suggested by the expression "disruptive critical voltage." As defined by Mr. Peek the "disruptive gradient" for air is constant; it is the same for all sizes of wire and cable and has the value 30 kv. per cm. The obvious objection to this definition lies in the fact that the air will break down under this gradient only in the theoretical case of infinite parallel planes, and that it may be subjected to far higher gradients in the neighborhood of wires and cables without giving any evidence whatever of breakdown or loss. Mr. Peek and Dr. Steinmetz, to explain this inconsistency, state that in the case of wires or cables the "disruptive gradient" must be reached at a distance from the surface. Now this means either that breakdown occurs first at a distance from the surface, a condition of which there is no experimental evidence, or that the first breakdown occurs at a higher gradient than 30 kv. per cm. Since it is certain that a higher gradient than 30 kv. per cm. can be applied to air without breaking it down, we are hardly justified in saying that its electric strength is constant, or in calling the constant term of my formula (1) [Mr. Peek's corresponding formula has no reference number], a "critical" gradient.

By producing the quadratic loss curves backward to the

Digitized by Google

voltage of zero loss Mr. Peek deduces a series of values of voltage gradient whose mean is very close to the value 30 kv. per cm. above referred to and this is his principle reason for defining this constant gradient as " disruptive gradient " as already discussed. This approximate constancy is extremely interesting as there is no obvious reason why it should occur. It must be remembered however that the quadratic law is obeyed with great accuracy by all the observations on the upper portions of the curve, whereas there is a rather wide percentage variation among the gradients calculated as above described, almost too wide to be attributed to experimental error. Further since the quadratic law is deduced from the portion of the curve above the visual corona voltage, and since the latter is always greater than that corresponding to the constant term of my equation (1), it may be that the approximate agreement of the zero-loss-gradient, as obtained by extending the quadratic curve backward, and the constant term is fortuitous.

A third reason for defining the " disruptive critical voltage " is that suggested by Mr. Davis in his experiments on the sparking voltage of two wires brought close together. He states that sparking sometimes takes place at lower voltages than those corresponding to corona voltage. I should be very much interested to see a more detailed account of his experiments and observations. There are several evident reasons which might explain a lowering of the sparking voltage below that corresponding to visual corona intensity. First, with parallel wires close together the equipotential gradient surfaces, if I may use the term, are not concentric with the wires. This means that the total circumference of such a surface is greater in the case of the parallel wires than in the case of concentric cylinders. This means that the volume of air involved in the strain of a given value of gradient is greater in the former case. We have already seen that in the case of larger volumes, as for example with larger wires in the case of concentric cylinders, the break down takes place at a lower value of gradient. Another possible cause for lowering of the sparking gradient is the drawing together of the wires by electrostatic attraction or a lack of true straightness. It is possible that errors of this nature were provided against, but the apparatus described by Mr. Peek shows a span rather long as compared with the small distances suggested by Mr. Davis.

Mr. Peek has accepted Ryan's conclusion that the disruptive critical voltage or rupturing gradient varies directly as the atmospheric pressure. He also finds from his own experiments that these quantities vary inversely as the absolute temperature. My experiments are at considerable variance with these conclusions. As regards temperature neither Mr. Peek's nor my own experiments are sufficiently extended to justify a discussion of their differences. In the matter of pressure however, my paper describes experiments showing that while the relation between

Digitized by Google

critical gradient and pressure is linear, it is not one of direct proportionality, and further the slope of the linear relation varies with the size of wire. Dr. Steinmetz states that there is no real discrepancy, and explains in terms of his idea of the storage of energy in an envelope of air around the wire. Among other things he states: "At lower air densities the energy of the dielectric field is less." This idea is also adopted by Mr. Peek in a reference to the Hayden-Steinmetz paper in which Dr. Steinmetz first introduced it. The suggestion is a novel one, but in the absence of confirmatory experimental evidence or further explanation of the form of the stored energy and of its relation to present physical theory, it is hardly possible that it will be accepted in explanation of the phenomena we are now discussing. Dr. Steinmetz makes some further interesting suggestions in his explanations in terms of the ionization theory. It is regretable that he has no interest in this theory. If there is one thing it does do it is to permit quantitative calculations; in the hands of Dr. Steinmetz, with his splendid power of analysis, I believe that many of our present uncertainties in this most fascinating field, would be cleared up, and new problems set before us. Professor Ryan remarks that my conclusions as to the absence of the influence of foregoing ionization on the corona voltage are in accord with his own, and that therefore my reference to his three wire experiment is pointless. Replying I would state that even if a distinction between "part corona" and "full corona" be granted, no conclusions are permissible from his experiment since the voltage gradients are necessarily different in the two conditions which he compares.

F. W. Peek, Jr.: When the investigations given in the present paper were first planned it was decided to erect a short experimental line to represent practical conditions, and to supplement this study by extensive laboratory work. A short line of this sort has the advantage over a long operating line in that there are no impossible corrections to make due to voltage rise and variable elevations, weather, temperature, etc., along the line. Thousands of readings were taken for various conditions. The present paper though quite long is necessarily very much condensed on account of the vast amount of material to discuss. While the formulae given cover any conditions to be met with in practice, as frequency range, natural range of barometric pressure, etc., it is hoped at some future date to go further into the relations determined, more from the speculative and theoretical standpoint. For instance in the expression:

$$g_v = g_0 \quad 1 + \frac{0.301}{\sqrt{r}}$$

$\sqrt{r}$ is probably the first term of a convergent series, etc.

Dr. Whitehead's paper deals with what comes under visual

Digitized by Google

test, Section VIII, of my paper. Dr. Whitehead is to be congratulated on the ingenious and accurate method which he has devised to determine the critical surface intensity and also upon the general arrangement of his data. In our laboratory tests we have preferred the visual method in determining the critical intensity as it has been found to give consistent results, is easy of manipulation, and the effects of slight imperfections on the conductor surface can be seen at once and eliminated. Dr. Steinmetz has pointed out that the discrepancies between Dr. Whitehead's paper and mine are only apparent. Thus g_0 should be independent of the frequency and proportional to the air density, but the visual critical gradient g_v, covered by Dr. Whitehead's experiments, should be dependent on, and increase with the frequency, to some extent, as greater energy is stored in the "disruptive envelope" for a given thickness, as the frequency is raised. For a similar reason g_v should probably vary slower than the air density. Thus theoretically both δ and f should enter the constant 0.301 in the relation between g_v and g_0. However this correction is very small in the practical ranges of frequency and natural atmospheric conditions. The ionic theory can nicely be applied here as Dr. Steinmetz and Professor Ryan have shown.

Dr. Whitehead objects to the term "disruptive critical voltage". As there is every evidence that two critical voltages exist, they must be distinguished. The term was introduced to separate this constant gradient critical voltage from the already known visual critical voltage. The various evidences of the disruptive critical voltage or a constant breakdown gradient for air are:

1. The e_0 of the quadratic law gives a constant gradient.

2. The e_0 in the equation $e_v = e_0 \left(1 + \frac{0.301}{\sqrt{r}}\right)$.

3. Observations of Professor Ryan and others, who have determined a constant breakdown gradient of air of about 30 kilovolts per cm.

4. The reason suggested in the discussion of Mr. Davis.

All the values agree in magnitude and point to this constant breakdown gradient.

Dr. Whitehead states that the g_0 values vary to a considerable extent. It must be remembered that these values were not determined on short lengths of carefully polished conductors in a laboratory as were the g_v values, but on weathered wires out of doors, on an actual line, and having a considerable range of surface conditions or irregularity factors. It also must be remembered that e_0 is not determined directly as e_v but by an indirect method which would also account for variations, as discussed in the paper.

Mr. Hendricks' experimental observations that the strength of air between two concentric cylinders is not a maximum when

Digitized by Google

the ratio of diameters is 2.718 as theory would at first seem to indicate, but at a greater ratio I think is what would be expected. Thus before the spark over potential is reached the inner cylinder has a much greater diameter, due to the conducting corona envelope, and the actual metallic ratio is not the true ratio.

Professor Ryan has added a very interesting and instructive discussion. Of special interest is the value of a that he has deduced. Thus he has taken values from his paper of 1904 and deduced values of a, the thickness of the "energy envelope", by the method described in my paper, for comparison. The close agreement between these values and those of the present papers is quite remarkable. Professor Ryan has also shown that this is in agreement with measurements made on spheres some years ago.

Digitized by Google

DISCUSSION ON "THE RESPONSIBILITY OF ELECTRICAL ENGINEERS IN MAKING APPRAISALS," "DEPRECIATION AS RELATED TO ELECTRICAL PROPERTIES." CHICAGO, JUNE 27, 1911. (SEE PROCEEDINGS FOR JUNE AND SEPTEMBER, 1911.)

(Subject to final revision for the Transactions.)

Bion J. Arnold: The question of the relationship of public utility corporations to municipalities is one to which I have given more or less attention during the past eight years, and consequently I may, perhaps, say something on the general question that will bear upon the first paper, and possibly point out one or two things with reference to the second paper which may be of interest.

In the first place, I quite agree with the first speaker, and with our President as outlined in his remarks this morning, that the engineer can perform no higher service to his profession or to the community than by becoming interested in this subject and endeavoring to get the public mind clear, or help it to make up its own mind as to what is a fair disposition of the various questions that come up before the various individuals composing the public and the public utility corporations. We are all familiar with the fact that the state in which the public mind has been for some years past is due largely to the fact that the corporations, or those having them in charge, did not look upon the public's side of the question as liberally as they should have done, at certain period's of the corporation's existence, and the fact that these oversights were made, created in the public mind a distrust of the methods adopted in certain instances by corporations. I think we will all admit that that supposition on the part of the public was fair in many instances, although on the other hand, it is not fair to assume it was always true of all corporations, but the fact exists, that the public got into that state of mind. When the public finally got in a position to require the corporations to do things which the corporations had not previously been doing, the public went to the other extreme, and exacted of the corporations things which were as equally unjust to the corporations as the injustices which some of the corporations had been perpetrating on the public in the past.

Fortunately, during the past three or four years the public has become more or less educated on the subject, and is treating the corporations more fairly, because the public is analyzing these questions more thoroughly and understands them better, I think this better feeling is due, first, to the fact that the public wants really to treat the corporations fairly, if it is sure that the corporation will treat the public fairly, and, secondly, to the fact that many members of this profession and other engineering professions have taken a hand in solving these questions and have been instrumental in educating the public mind as to what is fair between the public and the corporations.

Now, on the question of franchise values. Our original methods were largely wrong. All of us 20 or 25 years ago were engaged—

Digitized by Google

I say all of us, many of us, by the manufacturing corporations or the public utility corporations—in creating the electrical enterprises; some of them not electrical, because we are not all electrical here, but most of us were engaged in creating the electrical enterprises some of which have come up for public criticism since that time. We all went ahead at that time on the theory that the franchises were valuable, and therefore they would stand capitalization, and they were capitalized. Consequently, the public was required to pay a return upon not only the real cost of the property, but also on a fictitious cost, or an assumed cost, or an assumed value, rather, instead of cost, on these franchises. Now, taking into consideration the pioneer period during which these enterprises were created, it is not perhaps unfair to say that these corporations were entitled to an excessive profit upon the actual physical value of the properties of that day, and that, therefore, they were justified in assuming that the franchise had value, and in paying a rate of return upon these franchise values—I do not know that I will say franchise values, but partly upon franchise values and partly upon capitalization that it was necessary to put into the properties to replace the parts of the property that became obsolete during the rapid changes in the state of the art, thus introducing into the capitalization of the companies not only the question of franchise values, but also the question of obsolescence.

My position on that matter for the past three years, after having had five years to think about the subject and come to conclusions that I thought satisfied my own conscience is—that a public service corporation is justly entitled to have more than a fair return upon the actual money put in under such conditions, namely, pioneer times—that a company is entitled to excessive profits for those times, or if it should not make these excessive profits, it is entitled to live long enough to make a good profit not only during those times but also during its life, so that the people who put the money into the enterprises under great stress and great risk, shall make more than ordinary returns upon their money; for having taken the risk of the venture provided that when the company has earned and paid to the stockholders this profit, all excess over a fair return upon the value of the property thus performing the service shall be put into a fund to gradually amortize obsolescence and other values previously carried in capital account but representing no real property. I have recently put this plan into practice in one the of largest cities in this country—and got the corporation also one of the largest, to agree to it. The fundamental principle underlying that theory is this: That the public should pay, for instance, to a street railway corporation, the actual cost of producing the service which s given to the public, plus a fair return upon the actua capital necessary to create the property, and also that necessa y to continue its operation. In the case o: early railroads or railroad cre ted under pioneer conditions I would give

Digitized by Google

them much more than the present rate of interest; and in cases where the properties have operated at a loss during the earlier periods, I would allow the companies to maintain in their capitalization the actual cost of the properties plus these early losses, and I would allow them to continue to earn a higher rate of interest than what is now usually considered a reasonable rate on money, until they have earned back out of the property these early losses, and a liberal return upon the actual money they put into the property, which would cover not only the present physical value, but also the cost of such machinery and material as has become obsolete during the creation and operation of the property up to the present day.

This is upon the assumption that from now on the company is going to be regulated as to its rate of return by public service commissions, or by other state or municipal authorities and thus be prevented from earning excessive returns out of which to recoup their early losses—because the corporations when they went into these enterprises assumed they were going to be able to operate them long enough to get their money back, and make something more than an ordinary rate of return otherwise the parties furnishing the money would never have gone into the enterprises and operated them at a loss during the early periods. Now, the public may state its proposition in two ways—*i.e.*, it may say we will allow you to make large returns up to the present, but from now on we are going to regulate your rates, so that your return will be only the ordinary interest on your present investment. I believe that if the public is going to regulate from now on, it should see that the past losses, of the companies are taken care of and that the capital that went into the enterprise in the past should yield a liberal rate of interest up to date, and if the company has been honestly managed and has not earned that interest and also enough to make up its early losses and return the capital represented by obsolescence that this capital should stay in the capitalization until the company earns it out, and from that time on the company should accept what is considered now a reasonable rate of return upon the actual value of the property then providing the service and also that from that time on, all earnings over and above that rate of return should be put into an amortization fund, to gradually retire this capitalization represented by obsolete property, purchased during early operation, and other development expenses. I hope I made myself clear upon that point, because I believe it is fundamentally right that the public should pay the cost, plus a fair return, to the company that produces this service. It is right, when the company has earned back its money which it took to produce that service, that the public should pay a return simply upon the actual value of the property which is producing the service, assuming that the people who went into the project in the earlier days have made a good, liberal return on the investment.

Digitized by Google

Therefore, our present methods, or rather the methods of some of us who are engaged in endeavoring to straighten out some of the present difficulties, are as follows: We assume that these corporations have been organized under the above conditions, and have operated up to the present time, some of them with great success, and some with indifferent success. Those which have been operated with indifferent success are entitled to the consideration which I have mentioned, but those which have operated with great success, however, and have taken out of the property a good liberal rate of return, are not allowed to carry in capitalization this excessive capitalization any longer. In other words, if the records of the property show the property has been honestly and well managed and the rate of return, taking gross receipts, and deducting operating expenses, have not been enough to pay a good rate of return on the investment, the amount spent for obsolescence and for early losses should be kept in the capitalization, but if the records show that the company has made a liberal return on its investment and that the extra money has been declared in excessive dividends instead of creating a depreciation fund out of which to rehabilitate the property, then I say such a corporation has no right to claim the benefits of the plan just suggested, and it should be judged on the physical value of the property as it exists today.

That is the method which was applied to the valuation of the Chicago properties some five years ago, namely, that these properties, especially one of them, had earned excessive rates of interest for years, some of them as high as 35 per cent upon the money they cost, and consequently the people who owned the property received back many times over the money they put into them, and consequently there was no hardship when they had to accept a depreciated value of the property, namely, a value which represented the real property in existence, with the understanding that from now on, when the property has been rehabilitated and firmly established in such a manner that the securities of the properties are absolutely reliable, as the pioneer days are gone, the people who now put money into or have money remaining in these properties should be willing to accept a reasonable return from this time on, be that five, six, seven or ten per cent, whatever you agree upon—but it cannot be 25 per cent or 40 per cent, or something like that, because the money now invested in the properties, is invested in a stable investment, and we must accept it as such and the public utility corporations should recognize that those of them who have accepted this view of the situation are the ones who are getting along most successfully in our municipalities today.

On the question of values, in making a valuation of the physical property, of a public service corporation it is right, in my opinion, to determine, first, the cost to reproduce the property new, and in that cost to reproduce new must be considered not only the actual value of the physical property that you can go

Digitized by Google

out and find, but you must consider also interest during construction, engineering expenses (usually five per cent) legal expenses applicable to construction only—I do not mean attorney's fees incurred in the creation of the company, or the securing of franchises, or anything of that kind but only those applicable to construction work alone and a reasonable contractors' profit.

When fixing the rate a corporation should be allowed to charge for service there are sometimes other expenses which should be included in its development expense, such as preliminary technical expenses, legal expenses during the formation of company not connected with construction expense, cost of consolidations and reorganizations, sometimes a reasonable promotor's profit, supersession of equipment due to the rapid advance of the art, reconstruction due to unforeseen contingencies, brokerage, discount or premiums on securities, and sometimes franchise and "going" values, including losses during early operation, all of which should, however, eventually be amortized and eliminated from the value of the property upon which the public should be expected to pay a rate of return, although it is but fair that the company should have time to earn this amortization fund.

These are what are known as development expenses, usually running anywhere from 10 to 25 per cent of the cost to reproduce the physical property new. Some companies will contend and say it should be as high as 35 per cent. I never yet found a property where I thought such a percentage should be allowed, but have found some where 25 per cent was fair, some as low as 12 to 15 per cent, some 22 per cent, and I think that from 20 to 25 per cent is not ordinarily an unfair figure to add an order to determine the actual cost of reproducing new the physical property.

My time is short, and I have endeavored in a general way to outline my judgment regarding the subject of Mr. Byllesby's paper, which is a very valuable discussion of the general subject.

In regard to Mr. Floy's paper, he makes the point that the engineer must know for what purpose the valuation is being made, and states that so far as the value of the property to the owning and operating company is concerned, that is for its use a very low rate of depreciation should be considered. I am not so sure that that is correct. I maintain and always have, when you are considering a question of rate making, that the company asking for the rate, should be allowed a rate based upon the cost to reproduce the property new, taking into consideration the development expenses which I have mentioned, and that a condition precedent to that valuation, requires the property to be in first-class condition so as to be able to give first class service and if the property is found to be in bad physical condition, that the company has no right to ask that the rate be based on the cost to reproduce new, unless the company has in its treasury, or has somewhere a depreciation reserve fund, such as we

Digitized by Google

have in Chicago, provided of course it has been able to earn such a fund sufficient to put the property in first-class condition, so as to give a first-class service, which is what you require of it, and which is the condition you require it to be kept up to in order to entitle it to the rate you gave it.

Many communities will attempt to fix a rate upon the depreciated value of the property. I think that is a short sighted policy from the standpoint of the public, because if the rate is fixed on that value the company has no chance to raise enough capital to put its property in first-class condition, to give first-class service, and consequently the rate should be based upon the capitalization to reproduce the property new, or on the present depreciated value of the property, plus enough to put it in first-class condition, and that money must be in the treasury of the company, or in a fund for that purpose.

W. F. Wells: Mr. Floy has covered the subject of depreciation in such a broad and comprehensive manner that he leaves almost nothing to be said. However, I would like to voice my approval of the statement he makes, to the effect that in estimating the value of the property, only absolute depreciation be considered, and not any theoretical value of depreciation. I think that property which is in good order, and operating efficiently should not be depreciated when rate cases are under consideration. In other words, any company which is maintaining its property in first-class condition, so that its original utility is unimpaired, should not be compelled to depreciate the value of that property for the sake of rate making.

As to Mr. Byllesby's paper, I have heard one or two engineers take exception to the manner in which he has treated the question of replacement value of underground subways over which new pavements have been laid. A company is entitled to this increment value just as much as it is to the increment value of real estate or any other property. Companies frequently install subways in advance of new pavement in sections of cities where for years to come the gross revenue will not pay the fixed charges, but they do this on the idea that the difference between the original cost and the replacement value after the new pavement is laid will in part offset these carrying charges, such as interest and taxes during the time of nonuse.

Regarding the general subject of appraisal work, one of the most difficult and laborious features is to obtain physical inventory of the underground system of an electric light company.

I had occasion this spring to make a complete inventory of the underground property of the Brooklyn Edison Company, and the method followed may be of interest to some here.

The property was all recorded graphically on maps and records, contained in some twenty large volumes. On each page of these books were shown the details of the sub-surface structures in about 500 lineal feet of street, including the subways, man-holes, cables, Edison tubes, junction boxes, etc. The

Digitized by Google

problem was to tabulate and summarize the amount of each type of construction.

I determined that the Hollerith system, such as was used by the United States Government in tabulating and summarizing the statistics of census reports could be made the most satisfactory. We had all the necessary perforating, sorting, and automatic calculating machines, which were in use for analyzing our output and revenue, and after thorough analysis of our underground system, I found that by slight modification, it was possible to adopt these machines for making the inventory. The data on the record books was transcribed to special forms which were prepared, using one sheet for each page. In order that these data may be perforated on the templet cards, for the sorting and adding, it was necessary to indicate all descriptions in figures or key numbers. Every street in the city was given an arbitrary number, which, with the sheet number, completely indexed the sheets.

All types and characters of subway construction were indicated by nine figures, the first two indicating the number of ducts in the bank; the third, the material, such as tile, fibre or iron pipe; the fourth, the number of ducts wide in the trench. Two more figures showed the distance from the top of the duct bank to the top of the street pavement, the character of which was indicated by another figure. Two more showed the date of installation, thus; 16.5.4.06.1.07 indicate 16 ducts of tile laid four wide, and therefore four deep with six feet of cover between the ducts and top of an asphalt pavement during the year 1907.

For man-holes two digits showed the perimeter of the hole; the third indicated the character of cast iron head employed; two more the depth of the hole; another the material, whether brick or concrete; another the type of paving and two more the year installed.

For cables the first digit indicates the character of insulation; the second the number of conductors; the third the voltage; two more the size of conductors, and two more the year installed, thus: 4.3.2.2.5.07 indicates a lead covered paper insulated cable having three conductors for use on 6,600 volt service, each conductor being 250,000 cm. and installed in the year 1907. All quantities were naturally expressed directly in figures. After the record sheets were prepared, of which there were 3,800, some 33,000 cards were perforated, the operators being able to punch from 200 to 400 per hour.

These cards were of two kinds, one showing number and character of services, quantity and style of subway and duct feet occupied, the other showing the number and type of manholes, and length of various cables installed.

These cards are then placed in the sorting machine, which may be set to select any type of construction, after which the adding machine summarizes the quantities.

These cards and record sheets, with additions and withdrawals

Digitized by Google

now form a perpetual inventory of our underground property and are so indexed that any card may be checked at any time.

John W. Lieb, Jr.: I think that the Institute is to be congratulated for having had presented to it these two papers which are somewhat afield from the usual line of papers which have been presented before the Institute heretofore. We all of us, whether engaged in the railroad field, or the transportation field, or the electric lighting field, must sooner or later come face to face with these problems, and it is of the utmost value and importance that we shall have a fairly general view and grasp of the situation. If this is not the case, when we come to represent our respective interests before public bodies, such as public service commissions, or regulating state or municipal bodies, we will find it necessary to make our views known, perhaps inadequately, perhaps incompletely, through the medium of our attorneys.

Now, all of us who have had experience in trying to deal through our sister profession with technical matters must recognize the extreme difficulty and the unsatisfactory method of having to deal through a representing medium commonly unfamiliar with the technical expressions and the technical requirements of these cases. Therefore, I say that these gentlemen have done a real service to the Institute in calling the attention of the members to these questions, so that they shall become well informed and have presented to them in a compendious and complete presentation the gist of these matters, and Mr. Floy in his paper has presented what is a fairly complete list of definitions which certainly should prove extremely useful.

Unfortunately, in presenting matters on a subject of depreciation rates of depreciation are given in tables. It is very easy to apply them in a way to make them misleading. These rates of depreciation are usually based on the exhibition of the physical life of the properties of the apparatus, without taking into consideration the necessity of a very much shorter career, due to supercession, conditions of obsolescence, etc., and it is unfortunate that tables of depreciation do not specify that they do not cover obsolescence and do not cover any supersessionary reducing time limit. If you will refer to the table given in Mr. Floy's paper, and what follows, you will see how evident this is. Under arc lamp, for instance, the fourth item, rate of depreciation in per cent per year for arc lamps is six per cent. Now, we all of us who have been engaged in this business know how thoroughly inadequate any such allowance as that would be with these rapid changes that are going on in this field. The same thing would apply for instance, to the rate of six per cent, or 6.5 per cent for electric meters.

Now, we have had the assistance in furthering this rapid voyage from the operating room to the scrap pile of very many of the members of this Institute, and they are partly responsible for this continuous cycle of improvement. It is, of course, to

Digitized by Google

this continued cycle of improvement that we owe the immense expansion which this industry has had, but it also should be recognized that this continued cycle of journeys, of rapid journeys, from the operating condition to the scrap heap, should have its proper expression in what is the real and proper rate of depreciation, and if tables of depreciation do not include supercession or obsolescence they should so specifically state.

I was very much interested, indeed, to hear Mr. Arnold's statement of his views in regard to a matter of the very utmost importance to all public utility corporations, that is to make a reasonable and proper provision for disappearing assets, the physical assets which in the course of these consolidations and mergers that have already taken place, have disappeared, and it is a most unfortunate condition, for which our present financial conditions and lack of explanation is largely due that the public is misinformed, and considers that these disappeared assets are denominated by some of our friends as " water ".

Now, gentlemen, in bringing these vast properties together, and in order to give the public the advantages which they have received in large measure by bettered service or lowered rates, it has been necessary to scrap enormous quantities, enormous parts of the apparatus that have been functioning in some of these smaller corporations, which have been merged or consolidated into the larger institutions. Now, for this apparatus that has so soon gone out of use, and for which the larger corporation had no use whatsoever, securities were issued in good faith and bought by the investor, and yet the physical assets, as has been referred to, have disappeared, and when these valuations are made even the closest scrutiny and search will not find anything in the existing operating system that represents these disappeared values.

Now, I think that Mr. Arnold has, as a result of the deep thought which he has given to this subject, and of his experience, touched upon a very important and reasonable method of suggesting they take care of these assets which have disappeared, which cannot any longer be represented as inventory values, in the case of physical valuations of these properties.

It is most important that, as our President has stated in his opening address, which, I believe, should appeal to every engineer, that this is a field in which the engineer should rise to opportunities of wider usefulness. It is astonishing that public opinion should be moulded and shaped on these most important and vital questions relating to our industry by people who have not had the right experience of the business and who have not had information as to these repeated cycles of changes which are reflected in our business conditions, and it is up to us, as engineers, to do our part to shape and mould public opinion, so that not only the public shall have its fair, equitable and just treatment and consideration, but that the public service corporations also shall receive on their part that fair treatment

Digitized by Google

which the public, when it is once correctly informed, will not be slow in awarding to them.

Schuyler S. Wheeler: I have only two points to make.

First: It is evident that depreciation of the property of public service corporations is the important part of the subject as presented, but the titles of the papers are not limited to this. This difficulty would be met if the titles of the papers were considered as amended to read, "Depreciation as Related to *Public Service* Electrical Properties," and "The Responsibilities of Electrical Engineers in Making Appraisals of *Public Service* Corporations."

Second: It seems to me it would be much better if all kinds of depreciations of physical property were unified and classified, and a single rate of depreciation was universally adopted for each kind of article making up a property. I refer to the several ways in which depreciation is figured at present as illustrated under "Classes of Depreciation" in Mr. Floy's paper. I think he calls for both "absolute" and "theoretical" depreciation. These various rates of depreciation for the same thing, are intended to cover different circumstances, for example, the fact that on one hand a piece of apparatus may become very old and yet be wholly and fully useful to the owner, and, on the other hand if the apparatus is to be disposed of the value is very small.

Now I think that there is approximately a definite value for each piece of apparatus at different periods in its life; that such value includes actual wearing out and obsolescence and all of the other factors, and I think if we could arrive at some definite way to include all of these factors, and at a rate for each different kind of property, the problem would be very much simplified for us and many arguments would be cut out. I think it proper that in the conduct of every kind of business an amount should be charged each year against the earnings, representing that year's share of the reduction of the value of the property, and whether it be in a lighting company, a street railway, a manufacturing plant, or anything else, such charge should be deducted each year. If the property is considered each year as reduced by that amount the problem becomes quite definite and very much simplified.

E. Leonarz: Mr. Arnold called attention to the fact that a fair interest is allowed. Now, we certainly don't fear that rates would be increased, due to the original rates being too low. We have never heard that rates are being adjusted, when extensions of lines outside of cities have been asked for, but we hear that such rates are being lowered, or that lines are being extended from the previous limits, and the result is simply a higher investment, and sometimes that companies are going to the wall. Who is going to pay for these extensions and betterments? I think that such companies should be allowed increased rates, and that public service commissions should also take into consideration that only a part, and only a very small part, of the capital invested has received what we can call a fair return.

Digitized by Google

Public service commissions are also apt to take exception to the high rate of interest allowed to certain companies, which from the start, were led to believe that the field which they started in would really be better than it proved to be.

A. H. Ford: The question of reasonable return having been mentioned the speaker raises the question as to whether it is good policy for the controlling body to fix a single rate as a reasonable rate of return. He would answer in the negative; for if the management of a property knows that charges can be increased if this rate of return on the value of the property is not reached and will be reduced by the controlling body if it is exceeded, the incentive for operating the property more efficiently or with greater enterprise, is removed.

A better plan, it seems to the speaker, would be to fix the reasonable rate of return between certain limits as, for example, five and fifteen per cent of the value of the property; giving the controlling body the right to order a reduction of the charges only in case the rate of return is greater than the upper limit and allowing the management to increase charges only in case the rate of return is less than the lower limit.

Specifically; under the present plan there would be no incentive to replace an obsolete piece of machinery which involves a high operating cost by a new machine which would reduce the operating cost and thus allow greater earnings, which would be an invitation to begin action for a reduction of charges; while under the proposed plan this would be advisable. In another instance a reduction of charges might cause such an increase in the business that the earnings would increase but the management would hesitate to reduce charges if it knew that any increase in the rate of return resulting therefrom would be the cause of a further reduction until the rate of return was at the old figure. That this is not a hypothetical case is shown by the action of the Wisconsin Railroad Commission reported in the *Electrical World*, Vol. 57, p. 1599, in the case of the Madison Gas & Electric. Co.

Geo. L. Hoxie: Mr. Floy's paper is a timely one, upon an important subject. It is likely there will be little dissent from most of his conclusions. The table giving the rates of depreciation that have been adopted by various official bodies is particularly valuable, and the quoted extracts from various Court decisions are convenient for reference.

Certain features of the paper however, are likely to develop sharp differences of opinion. I would take exception to the notion of " absolute " and " theoretical " depreciation, and to the idea that " theoretical " depreciation must be provided for only as a part of operating expense, while " absolute " depreciation, for which Mr. Floy indicates quite a different value, is to be used as the basis on which rates are to be fixed, capitalization allowed, etc.

It does not seem that such a division of depreciation into two

Digitized by Google

values, one to be used in one case, and one in another, is at all possible as a practical matter and if it were tried I believe that it would quickly lead to an intolerable situation. In a rate fixing matter for example, the Board, or Commission, fixing the rates would, under Mr. Floy's theory, assign a value to the physical property based upon what he terms "absolute" depreciation, which it seems would usually be very close to the first cost of the apparatus considered, (as in the case covered by the St. Louis decision, so approvingly quoted.) Then the Commission would fix a yearly *rate* of depreciation, and this rate of depreciation would perhaps be more *per annum*, charged to operating expenses, than the *total* "absolute" depreciation.

After rate regulation had gone on for a few years, say 10 years, we should have a fund, paid out of operating expenses, equal to perhaps 50 per cent of the first cost of the plant, and this fund, as would ordinarily be the case, has perhaps been largely expended in extensions and improvements to the plant, (to the extent of keeping its "theoretical" total value constant); but the property of the Company, based on "absolute" depreciation would, if maintained at full operating efficiency still be figured at within a few per cent of its original cost or would be, on this theory, (with a "theoretical" rate of say 5 per cent, nearly 50 per cent more than the first cost of the original plant, at the time when rate regulation started. Yet all of the excess value upon which rates must then be based, has been contributed by the consumer. The consumer has thus paid for the privilege of paying dividends to others on his own payments to them. One can see readily enough that this theory carried out over a term of years would mean rates so high that any Public Service Company should be able constantly to increase its physical property, without any additional capital investment, meanwhile paying full dividends each year on the increased value for that year.

Of course, something of the sort is what has actually gone on in the case of many successful Public Service corporations; but it is precisely such a state of affairs that has brought about rate regulation. Some important Public Service enterprises have mainly been built out of excess earnings. Once built and the excess earnings capitalized, it is impossible for the public to go back, and in effect take away property from stockholders, on a plea that it was paid for by the public out of excess earnings.

If now, we base plant value on one rate of depreciation of plant, and allow operating expenses on a rate of depreciation that is many times higher, we have made no improvement by our rate regulation. On the contrary we have made matters worse, for, under rate regulation, we have eliminated the competition that formerly limited rates, and we have in effect guaranteed rates sufficient to pay dividends on unjust values. The thing cuts both ways. You cannot charge depreciation in your operating expenses unless you lower your estimated plant value by the

Digitized by Google

amount charged to operation for depreciation, less the amount put back into the plant. The total "lessening of worth" of a plant during ten years is the sum of the depreciations for each of the ten years—of course less any money put back into plant: In my opinion, with a new company, starting under rate regulation, and having rates permitting fair payment to capital and the charging of straight line depreciation to operation, the value of the physical plant must, each year, be reduced by precisely the amount of the depreciation fund remaining unexpended at the end of that year. The Company must also be allowed to call any unexpended balance, capital, and to earn dividends upon it, crediting earnings of course with any income the fund may have produced.

As a practical matter the depreciation fund of any large company cannot be made up of a lot of separate accounts each balancing the "lessening of worth" of some one item, but it should be a fund balancing the total lessening of worth of all items together. Also as a practical matter, the depreciation fund would not be held in cash for any great length of time, but should be invested, so as to produce a revenue. Of course the investment may be in any form of property, perhaps in the bonds of other companies, or perhaps in the bonds of the company itself. But the most usual form of investment will doubtless be in *new plant construction*. Such investment should yield the greatest possible return, and should provide in the best possible manner for balancing the depreciation of the previously existing plant. If an exactly correct rate of depreciation be determined and so balanced by a fund, used in extraordinary repairs, extensions, new constructions, etc., the physical value of the plant will remain constant (unless new capital be also used in construction).

Since no human measurement can be absolutely exact, care should be taken to see that the rate of depreciation chosen is a little too high rather than a little too low, otherwise the company will in time be wrecked. With a depreciation fund a little too large constantly being put into improvements, the value of the property will constantly appreciate. But the public, in the form of a commission, may very justly step in at this point and prevent any increased capitalization or earnings on account of such increased value; but may say to the Company, "This increased value is not yours, but belongs to the public, since it exists solely because we, in our care not to wrong you, purposely allowed you to collect somewhat too large a depreciation fund."

It is easy to see that under such a financial scheme as here outlined, a corporation's bond and stockholders would become more secure each year as to the safety of their original investments, yet they are not allowed any "unearned increment." There would probably come a time when not merely 75 per cent or 80 per cent but perhaps as much as 100 per cent of any additional funds needed for extensions, could be had from low rate bond issues. The public, on the other hand, would get the benefit of steadily decreasing rates.

Digitized by Google

A much more difficult situation, and perhaps such a one as Mr. Floy had mainly in mind and attempted to meet by two rates of depreciation, is found where a public service company having handled its business as it pleased for many years, suddenly comes under rate regulation. Such cases are almost the usual ones now. It must be admitted at once that fixed rules are almost impossible. Each separate case is of a corporation whose history is somewhat different from every other one. Some corporations have been conservative, some reckless; some have had good engineering, and some no engineering; some have maintained depreciation funds, some have largely built their properties out of excess earnings, and some have capitalized everything, watered to the limit, made no proper provision for depreciation, and perhaps the promoters have withdrawn with personal fortunes, leaving a lot of deluded stockholders, a run down plant, and a new rate making commission, to be dealt with.

About the only general rule that can be laid down is that each case must be treated with common sense at the start, and that the treatment must look toward the establishment. as quickly as possible, of such conditions of business management as would be enforced at once on a new concern.

There can be no doubt that a " theoretical " rate of depreciation must in every case be charged against operating expenses. Possibly, to begin with, the theory of a lesser " absolute " rate of depreciation might bring out a common sense result in some cases, and *for a limited time.* In my opinion however, there is no case, and there can be no case, where the continued use of two separate rates of depreciation, applied to the same property, over a considerable series of years, will not bring disaster.

The real difficulty in making an appraisal of machinery in use, lies in what is almost the impossibility of correctly estimating the remaining period of life of the machinery, during which it will be of effective service to its original owners. This is a different matter from estimating the useful life of the machinery alone. Many a machine sold second hand, for approximately scrap value, has a long period of useful life ahead. But for its original owners the machine's life ended when it was discarded.

An engineer making an appraisal must not therefore limit himself solely to the physical condition of each machine. The physical condition of property may be the smallest factor of its value. In some way or other, the appraisal must be made to include a deliberate judgment of *value of useful service remaining*, in that situation, or to that company, plus salvage value. To say that an engineer can make such a prediction accurately for any given machine is to say that he can predict not only future advances in the art, but how many years ahead those advances will come. The best that the engineer—or anyone else— can do, is to judge the future by the past. He may say that various classes of machinery have in the past had such and such periods

Digitized by Google

of life. He may increase those periods by an amount that in his judgment it is fair to allow, assuming that future progress will be less rapid owing to greater standardization. He may then apply a depreciation based on age, and years of service remaining, and while method and result may be criticized, both are likely to be more nearly right than any other yet suggested.

Objection comes mostly from a general sense that injustice may be done to innocent stockholders, where application of straight line depreciation would make a drastic reduction in capital, of a sudden, which could not have been anticipated. In such cases the public must share responsibility for not having regulated matters earlier and a commission may reasonably, for a time, allow capital, and earnings, on some sum in excess of actual value as depreciated, and may thereby in effect assess upon the public some part of the loss due to bad financial history, which loss the public and the aforesaid innocent stockholders then share, upon some basis to be determined by the commission.

Conflicting Decisions. The Master's Report in the Consolidated Gas Case, from which Mr. Floy quotes, seems at first to be opposed to the method of estimating depreciation just outlined. As the Master's opinion was sustained by the Supreme Court, it seems a little presumptuous to differ—yet other decisions do not indicate that approval of the Master's Report constitutes a final pronouncement concerning the method that we must follow. The Master approves an estimate " based on a detailed examination of the property as it stands to-day." No one could object to such an estimate if correctly made. Such an estimate would necessarily consider not merely physical condition, but probable length of future service; and it is evident from the Master's opinion that he actually did consider the plant in condition to give service over a long period to come. It must also be noted that while a straight line depreciation is well within the possible limits of accuracy for any case where the length of life is short, in cases where the estimated life is long, as in the Consolidated Gas Case, a moderate rate of interest for the fund makes the annual charge against operating expenses very small. A sum amounting to a few per cent of the first cost, set at interest at the end of half the estimated life might in many cases reproduce the property at the end of its theoretical life. It does not seem possible to get more than a meaningless figure from a computation based on a life of 100 years or more. In Mr. Floy's curves, Plate 1, the annual charge to cover depreciation, at 5 per cent on 100 years of life, is practically nothing. The fund and interest, accumulating even at the end of 10 years, can hardly be read on the curve. In fact any estimated life beyond 60 to 75 years might reasonably be called perpetual life, for no computation, based upon such a life will be within the limits of error introduced by other uncertain factors, not the least of which is the estimated life itself. It seems clear therefore that the opinion in the Consolidated Gas Case by no means tells

Digitized by Google

us not to figure straight line depreciation in the case of an electric lighting or railway plant, having a probable life of less than 20 years. Certainly it does not tell us to figure two kinds of depreciation, one to use for an operating charge, and the other for a capital charge.

Curves of Depreciation. In Fig. 1 of Mr. Floy's paper are given six curves, as illustrating ways in which depreciation actually takes place. Curves 1 and 2, are based on selling values, assuming that the depreciated property is sold for use elsewhere. As the author says, depreciation of a going property should never be figured on the basis of these curves—unless the property depreciated is of less value to the seller than to the buyer, and in that case the property should be considered as scrap, and not included at all in a value of the property on which for instance, rates are to be based. Curves 1 and 2 therefore are not truly such depreciation curves as may be used for going properties. Curve 6 is for property which it is assumed will be kept at close to 100 per cent of operating efficiency until just before the end of its life. It seems that the reasoning given in connection with curve 6, while at first sight plausible, is in fact wholly misleading. Assume, as shown by this curve, that a property gives precisely the same service at the end of the 17th year of its life as at the end of its first year. Also assume, as the curve also assumes, that at the end of its 20th year it has only scrap value. Decided the "fair value" of the property is very different at the end of one year and at the end of 17 years. The property value is due to its *remaining capacity* to serve—not at all to the *momentary character* of its service. Curve 6 cannot even approximately illustrate possible true depreciation. The curve is not really a depreciation curve at all, but is in fact a curve whose ordinates represent operating efficiency, at the end of any given time—quite a different thing.

Curves 3, 4 and 5 are the only curves of Fig. 1 that may fairly be called depreciation curves for an operating property. Mr. Floy calls these, curves of "theoretical" depreciation. It would seem better to call them curves of "actual" or "real" depreciation. The only uncertain point is the length of life. Give the real length of life of the property, and curves 3, 4 and 5 are not at all "theoretical", but very practical and definite.

Interest on Depreciation Fund. Curve No. 4, and the similar curves of Plate 1, show the effect of interest rates, assuming that the gradually growing depreciation fund is kept at compound interest until the life of the property is over, and is then exactly sufficient to replace the property. Curve 3 illustrates what is usually called "straight line depreciation."

There is something to be said on both sides of the question of whether to include interest computations, or to use straight line values. Personally I much prefer the straight line method for all ordinary cases of property having a life not over about 25 years, the objections to including interest figures being,

Digitized by Google

1. It is not practical, or desirable, to have an actual fund against each piece of property, maintained as an invested fund during the property's life.

2. If the fund be general, against the entire physical property, it will be drawn from, at varying times, and usually invested in plant extensions, none of them specifically replacing any especial part of the old plant, but all together maintaining the total physical property at a constant value.

3. It is difficult, and perhaps impossible, to estimate in advance the probable life of property so closely, that the error will not usually be greater than the difference between straight line, and curved line, depreciation. (For very long lived properties this might not be true.)

4. Rates of interest will not be constant during the life of a property, and will depend largely on whether the fund is kept in bank, used in purchase of bonds, or re-invested in extensions. One method may result in a rate of interest twice as great as another.

5. The straight line method is far simpler.

Even where statistics are so accurate as those of human life, it is found that progress in sanitation, medicine and surgery, together with the strict examinations of the physical condition and family history of applicants, has resulted in an average length of life of insured persons, appreciably greater than indicated by the tables.

It would seem impossible to estimate the average useful life of 1000 similar dynamos with such accuracy as to justify the inclusion of interest. For one thing there may be quite a difference of opinion as to when a dynamo is really "dead". Furthermore the salvage value at the end of the period of life cannot be estimated at the beginning of life. There are other similar uncertainties none of which occur in the problems of a life insurance actuary.

It seems therefore that such account as it may be desirable to take of interest on fund, at least for the depreciation of electrical machinery, might usually best be considered as a lengthening of the life period; using always "straight line" depreciation.

Fifty Per Cent Method. The "fifty per cent method" in certain cases, such as those mentioned by Mr. Floy, is quite a satisfactory one. It implies a relatively short life, or the inclusion of an interest factor. It should be noted that there is nothing theoretical about the depreciation where the fifty per cent method is applicable. Take the case of the incandescent lamps, on customers premises, of a company furnishing free lamp renewals. Some lamps are new, some just ready to be exchanged, and others of all ages between maximum and minimum. No one would maintain that the total value of stock, old and new together, is not close to 50 per cent of the new value. Also it is evident that the renewal of lamps as they become burned out or blackened keeps the whole outstanding stock at

Digitized by Google

about a constant value, making no special additional charge for depreciation necessary, except as lamps may become cheaper due to improvements in manufacture, etc., or as new types may make the old ones less valuable.

The question of when the " fifty per cent method " should be used is one requiring careful judgment. It is interesting to observe that when the Third Avenue Receiver, as Mr. Floy tells us, refuses to provide for depreciation, on the plea that the property has so many elements that all deterioration is simply wear and tear, and to be charged as maintenance, he really applies the " Fifty per cent method " to his entire system, and in effect inventories his property then and there at 50 per cent of its replacement value. If he is correct in his notion as to maintenance, the system may be easily appraised.

Use of Terms. The suggestions made by Mr. Floy on the subject of a more general agreement on terms are very wise. It would seem appropriate for the Institute, through some of its committees, to take up the whole question of terminology in connection with depreciation, and assign very definite meanings to the commonly used terms, and perhaps to coin new words if desirable. Such a committee might well work in connection with committees from the other societies, as all are equally interested.

P. H. Thomas: Mr. Floy has given us a valuable paper on the subject of depreciation and has clearly brought out a number of matters which are at present the subject of wide controversy. There seems to be an endless line of opinions and theories as to what constitutes the logical basis for the disposal of many of the questions arising in assigning depreciation rates in actual cases and more broadly in the matter of the determination of rates and utility investment values. Such matters are good will, promotion expenses, cost of building up a business, insurance, engineering, etc.

Is it not clear, however, as a matter of public welfare, and common sense that there is but one sound and logical rule by which all such questions must be judged, namely, whether under the ruling proposed the capital invested will receive a sufficient return to warrant its leaving other available lines of investment for public utility plants, this being the sort of property now under discussion. The community must have its utility plants developed and extended continually, and while it is under no obligation to contribute in any degree for the benefit of the capitalist, it must make its offer attractive enough to secure takers. It may be and in fact is possible to force a company which is already involved in a particular plant to do things it is inequitable to require and even to make some extensions to save a portion of the investment already made, which cannot be withdrawn, but this policy would in the long run end in stopping all development and furthermore is obnoxious to our sense of justice.

Digitized by Google

From this point of view it is relatively easy to determine the disposal of many of the disputed questions. Would the particular expenses sought to be added to capital account be necessarily incurred were the plant to be reëstablished *under the original conditions*? The costs of preliminary studies, within reasonable limits, the costs of engineering, insurance, the cost of building up the business, the losses and inadequate profits during the early years, interest charges, and all such expenses are necessary steps in the establishment of such a plant and are a legitimate part of the investment. On the other hand, the cost of mistakes, bad judgment, discounts or profits which are paid to persons or corporations for some reasons other than the necessity of the plant itself would not be legitimate additions to the capitalization. This exception should, however, be noted that a suitable percentage added to actual cost due to mistakes or accidents, etc., should be allowed to the extent actually found in similar undertakings carried out with average good judgment. Promotion expenses should usually be small in public utilities as such systems usually grow from a small size with the development of the community.

On the basis here set forth the cost to reproduce new is not a fair measure of the value of the plant. It should be the cost to reproduce again under exactly the same conditions that existed when the plant was actually developed. But in practice on account of the great difficulty of fairly determining such a cost under the old conditions it is customary to determine the cost new as a guide. Many appraisers in relying mainly on the cost to reproduce new seem to consider that the records and books of the company are so confused and interlaced with legitimate and illegal expenditures that it is hopeless to try to sort them out. This is a dangerous precedent from the point of view of securing fresh capital and suggests the importance of keeping the books so that legitimate expenses can all be shown, with their justification, at a later period, and with enough detail so that suspicion cannot be thrown on the totals.

There is another aspect of these discussions which has not been very clearly stated. In most cases of the determining of depreciation or in rate making, we may either strive to determine what the precedents of the courts state to be the law, leading to the probable immediate holding in any given case, or we may consider what is the ideal or logical or wise or fair determination. While in one sense the precedents of the courts are fixed rules, it is nevertheless true that the decisions must ultimately meet the sense of public fairness and good policy, either through additional legislation or otherwise and that the continual discussion of the ideal, that it may be clear and well recognized, is of the greatest importance to the community. It is gratifying to note that the spirit of intelligent fairness seems to be rapidly spreading, in spite of certain somewhat radical tendencies that appear.

Digitized by Google

Wm. A. Del Mar: In the summary of his paper, Mr. Floy gives first place to the following feature.

" The necessity of a more general agreement on and uniform use of the terms used in considering and discussing the subject of depreciation, by the engineering profession."

Mr. Floy is to be commended for pressing the importance of this point, for in most of the literature on the subject of depreciation the meaning of the principal terms has to be painfully ascertained from the context. Unfortunately our author, while generously assisting others over the pitfalls of loose phraseology, himself falls into them, dragging the reader into the very trap that he set out to save them from. For example, he defines the word depreciation in two different ways. The first definition is as follows.

" Webster defines ' depreciation ' as the act or state of lessening the worth of and in this sense it will be used by the writer. . .".

The second definition which occurs only twenty lines after the first says that " depreciation has been used to mean—"

" The annual amount expressed, as a percentage or in dollars that should be laid aside to renew or replace the article in question at the time of its abandonment, plus the annual expense of maintenance of repair expended in removing such part of depreciation as is practicable and good economy. This then includes all classes of ' lessening of worth ' and is the application of the term preferred by the writer. . . .".

The first definition says that depreciation is the state of something and the second, that it is an amount that may be expressed in dollars. If both are to be accepted it must follow that " states of something " can be measured in dollars, a point of view that opens up a new era in political economy and the theory of dimensions! I fear, however, that science is not destined to be enriched by such a discovery, as many readers will notice that the second definition is invalidated and rendered useless by the fact that it defines depreciation in terms of itself.

Later in the paper, wear and tear, decrepitude, supersession and obsolescence are defined as classes of depreciation. It is obvious that our author here follows his first definition, but with the result that he tries to measure supersession and obsolescence in dollars, which is impossible because the physical dimensions of these two quantities are indeterminate while that of a dollar, as explained below, is determinate and known. If Mr. Floy had defined depreciation as a lessening of value and then said that supersession, obsolescence, etc., were *causes* (not classes), of depreciation he would have kept out of this confusion.

If carelessness occurs in the definition of depreciation, what shall be said of the following use of the word valuable?

" On the other hand, apparatus that is in use and rendering a service economically, may for the purpose for which it was intended, be as valuable as when originally installed, although its age may be approaching the limit of its life."

Is it possible that our author does not distinguish between

Digitized by Google

" useful " and " valuable ", that he uses the latter term to mean the former? Apparently not, for it is obvious from what follows that the confusion is one of ideas and not merely of words. Thus, curves 1, 2 and 6, he says, " may be taken to represent absolute depreciation " by which he means *loss of utility*, while curves 3, 4, and 5 represent " theoretical depreciation " by which he means *loss of value*. The fallacy of Fig. 1 is the attempt to measure utility in dollars which are obviously incapable of measuring anything but value.

Another example of the confusion of the terms value and utility occurs under " Service Value."

" Physical property, honestly and intelligently purchased with a view to its suitableness for the service intended, aside from some hidden defect or untoward accident maintains its original value practically throughout its life, etc."

Does Mr. Floy mean value where he says value, or does he mean utility? This is only one case out of a score, where the meaning is doubtful, and the same criticism applies to many other words.

Leaving the field of corrective criticism and entering that of constructive thought, let us consider a few definitions which are not open to the objections cited above.

The *value* of a commodity or service is the inverse ratio of the amount of that service or commodity, to the amount of another service or commodity which it can be exchanged for. Value is therefore a ratio and according to modern political economists, is proportional to the ratio of two numbers, one of which is the ratio between the demand and supply of a service or commodity at a given place and time, and the other the ratio between the demand and suppl yof another service or commodity at the same place and time.* Expressed mathematically it is as follows:

$$\text{Valu} \propto \frac{\frac{D}{S}}{\frac{d}{s}}$$

where D and d represent demand and S and s represent supply. The physical dimensions of value are therefore undeniably those of a ratio or number.

The magnitude of the ratio appears when an exchange is effected, or proposed and therefore to all intents and purposes is nonexistent without an actual or potential exchange.

Just as an angle is measured by the ratio of its magnitude to the entire circle, so a value is measured by the ratio of its magnitude to the entire sum of exchanges effected in some arbitrary time, say a year. The equation of value and money is as follows:

$$A = D\ V$$

*Science of Money, Alex. Del Mar.

Digitized by Google

where A = value of the sum of all the exchanges effected with money, per annum.
D = number of dollars in circulation.
V = number of times per annum that each dollar is used, usually called the velocity of circulation

Expressed in terms of their ultimate physical dimensions

A is a value, which is a number, divided by a time or $\left[\frac{1}{T}\right]$

D is a number represented by [1]

V is a number divided by a time, or $\left[\frac{1}{T}\right]$

Hence our equation checks by dimensions $\left[\frac{1}{T}\right]=\left[1\times\frac{1}{T}\right]$

The time element may be eliminated from the equation by dividing each side by T. Performing this elimination we obtain $a = D\,v$, where v is the number of times each dollar is used while exchanges to the value of a dollars are effected with money. Hence an exchange which involves $1/n$ of the total value of all exchanges will require $1/n$th of $D\,v$, which therefore is the measure of value involved in that exchange. The physical dimensions of $D\,v$ are the same as those of D, that is to say a number. All this is very simple, but the number of people who write on depreciation and don't know it, is legion.

Value being a number and its unit also a number, the physical dimensions of *money* are those of a number, and do not involve time, mass or length. Hence money cannot measure anything that involves time, mass or length. Now utility is not a ratio or number; it is a complex quantity incapable of mathematical expression and having no unit. A gold nugget might have been useful to Robinson Crusoe, but its value in dollars on Crusoe's island was certainly zero. Utility not being reducible to the physical dimensions of money it is as futile to try to measure utility in dollars as to measure distance in pound weights. Yet by disguising loss of utility under the name of "absolute depreciation" Mr. Floy attempts to perform this impossible feat. By substituting "percentage of original utility" for the word "dollars," in his Fig. 1 our author would have made his meaning clear without using absurd expressions, although an attempt to measure utility or any other quantity having no unit is apparently vain.

This excursion in to the realm of elementary monetary science seems necessary because depreciation relates to a change in value expressed in money and this change cannot be clearly understood without a clear conception of what it is that changes.

Another element in the conception of depreciation, is *deterioration*, which may be defined as any change in a property due to wear and tear or the ravages of the elements, which tends to

Digitized by Google

impair either its usefulness or its life. Akin to deterioration, is *loss of useful association*, which may be defined as any change in the associations of a property, which tends to impair its usefulness or life. Finally before coming to depreciation itself, it is necessary to define *obsolescence* as loss of commercial utility in any property, due either to the advent of superior substitutes or to its own inadequacy to meet new conditions.

Depreciation may be defined as a lessening of value due to deterioration, loss of useful association or obsolescence.

Deterioration can be approximately predetermined from the results of experience, while loss of useful association and obsolescence are of a more speculative character and less amenable to computation. While, therefore, it is possible to estimate to some degree of accuracy, how much it will cost to overcome deterioration, it is possible only to bet or insure against obsolescence and loss of useful association.

The expression *replacement cost* means the cost of replacing an existing property by a new one either identical with it or possessing equal utility.

On account of deterioration, it is necessary to make replacements and repairs. Those replacements and repairs which occur frequently, or which severally cost a small portion of the whole replacement cost, should be made when required, paid for out of the annual earnings and charged to direct operating expenses. Such charges are called *maintenance* charges.

Replacements which occur infrequently and which cost an important proportion of the whole replacement cost, cannot be paid for out of the annual earnings without causing exaggerated operating charges in given years, unless a proper sum is set aside each year to provide in advance for the impending replacements. Such a sum is called a *depreciation charge* and the accumulated fund made up of these annual sums and the interest thereon, if invested, is called a *depreciation fund*. Considering only those elements of a property whose depreciation is offset by a depreciation fund, we may state as a general principle, that the ideal condition is that the depreciated value plus the depreciation fund should at all times be equal to the replacement cost.

This completes a set of definitions which are proposed in place of the corresponding ones used in the paper under discussion.

Mr. Floy's paper contains a great deal that is valuable upon this important subject and it is to be regretted that the presentation of such an elaborate research should be disappointing in the very feature that its author apparently set out to perfect, namely the uniform and correct use of the terms used in the discussion of depreciation.

F. W. Harris: Mr. Floy says that by the second plan consumer saves 25 per cent. I do not think this is so broadly considered and I cannot see that the consumer saves anything with prevailing interest rates considered. What happens is that each year the corporation borrows an additional $100,000 and charges

Digitized by Google

the interest to the consumer. This is fair to the consumer and if the rate of interest is a fair one is financially equal to paying it. This is readily seen if the consumers are considered as each year putting aside $100,000 at 6 per cent and each year paying the interest therefrom plus $60,000 to the corporation. At the end of 50 years the consumers will have a sinking fund of $5,000,000 and the corporation will have a debt of $5,000,000.

While, however, such a course as outlined in the first plan is fair to the consumer and practically equivalent to the second plan it is suicidal to the corporation due to the difficulty of properly securing this loaned depreciation. The corporation is in reality loaning its customers $100,000 a year without security. Such a course would be the height of folly but there are many corporations today which are on a smaller scale persisting in just such a course.

Mr. Floy's paper is aimed at such and is to be commended but his statement regarding consumer's position does not seem to me sound and as this is an important subject I have ventured to comment as above.

Horatio A. Foster: Mr. Floy has covered quite fully in his paper about all the ground work of the subject but I wish to add to his definition of the word depreciation the following: theoretically, depreciation of an object is that deterioration in its value that cannot be made good by repairs nor can it be made good in any way except by full replacement or renewal. From a bookkeeping standpoint we must get away from the ordinary conception of depreciation that it is just wear and tear because in making the changes on the books the wear and tear and what is termed deferred maintenance are all chargeable in operating expenses. In evaluating a property, however, all these conditions of wear and tear and deferred maintenance are considered with the depreciation the definition of which thus becomes, *any lessening of worth at the moment of appraisal.*

With the possibility of repeating I will try to add somewhat to the discussion. Every piece of physical property begins to wear out or deteriorate the minute it is started in operation. To be sure in many cases this is very slow, in very many cases it is not only slow but if there were no obsolescence or inadequacy it would probably give good service for many years. But as it continues to wear out, and as repairs are continually made in the endeavor to keep the property up as near its original value as possible, it is probable that the average of the lack of repairs on a whole property would approximate 15 per cent or if the property were maintained in very high class condition the average of this lack of repairs might be 10 per cent. It is utterly impossible, however, that taken at any moment, the value of the whole property could be 100 per cent of its original cost. I am speaking now, of course, of the original property only and not additions thereto. Therefore, in order that the capital may be maintained at its full value, it will be necessary to have ac-

Digitized by Google

cumulated a surplus or depreciation fund, or renewal fund, covering this 15 per cent, or the capital will be reduced in value just that amount. There is another method which Mr. Floy has touched upon but which I think deserves a little larger notice and that is what he calls the "fifty per cent method" of depreciation. This is only applicable to such large numbers of items of the same kind or nature as depreciate in common and as they wear together through a cycle of repairs, get into one general average condition, for it can be mathematically proven that when a number of articles such as a number of street car motors have all been in the shop for putting into thoroughly good order, the value of these motors new may be decreased by one-half of the total cost of the total repair on a motor; that is, the value of each one of the lot will be first, the total value of that portion of the motor which can not be depreciated, or that portion we might say which is always worth scrap value, or may be said to be worth a certain arbitrary value, say 25 per cent, of the cost new, plus one-half of the cost of the total repair to the motor; that is, the cost of repairs to everything that can be repaired.

Speaking electrically, the question of depreciation in connection with arc lamps, meters, and pole transformers should be given thorough consideration in any valuation, for the reason that these smaller items change in type so fast, wear out so soon, and are changed around so much that they are of no value at the end of 10 years, and often in much less time. In fact, I believe the larger companies depreciate them fully 1/10 per annum, for the reason that they go out of style so soon and that new forms are produced to replace them which are so superior that no excuse can be found for holding over the old ones.

It would be interesting to learn how Mr. Floy would treat the property of the Massachusetts street railways some of the values of which have been entirely wiped out by re-organization. For example, take the property of the Springfield street car system which was a good type of horse railway, and when it was electrified nearly the entire property then existing had to be abandoned, the horses sold, the car houses rebuilt or removed, the stables destroyed or used for storehouses, the track entirely reconstructed, and to this cost was added that of the power-houses, new car houses and new cars, all of the old ones being of no use under the new construction.

If an appraisal of the property of the Springfield Street railways were to be made at this moment the only values found would be those of the electrified property and nothing would be found of the original possessions covered by the first capitalization except the land. The question is, what has become of this original capital, and still further, what has become of it on the books of the company, or how has it been treated by the Massachusetts Railway Commission? It is the writer's view that an amortization fund should have been established to gradually wipe out the original capital, or perhaps better say, the cost of the original road.

Digitized by Google

As a matter of fact, we are all merely guessing at depreciation and its extent as no electrical apparatus has yet been installed for a time long enough to determine its actual life. I think I am safe in saying that no one in this room has ever seen a worn out Corliss Engine and it was the writer's pleasure recently to have seen the first three-phase dynamo installed; that at Redlands, Cal., which was put in place in 1895, I believe, and is still doing most excellent duty.

J. G. Hirsch: Probably no discussion is of more general interest to the engineering profession than one covering some phase of what might be styled engineering finance or accounting, such as that by Mr. Floy. The ultimate analysis in most engineering undertakings is in dollars and cents, and the weakness of engineers on cost and its analysis is an old story. The advent of Public Service Commissions and the necessity for satisfactory, detailed discussion of the financial aspects of especially the power projects of today must force the engineer to the fore on the subject, due to the fact that he has the pre-requisite understanding of the technical considerations.

In making estimates, I feel certain that it has been the custom of many engineers to give little more consideration to provision for, and operation of, depreciation, than to setting down a certain rate for the interest on the investment as a fixed charge.

The application of the terms depreciation, obsolescence and amortization has been bewildering to me. This much can be said, that they all *operate* as a charge on the operation of the enterprise. The acceptance of a single term, depreciation, and its proper definition, reduction of worth, will eliminate confusion. The term should not be confounded with the annual depreciation "charge", which is made to provide for the "loss of worth", or the "depreciation fund" or "depreciation reserve fund" (the latter to distinguish from a sinking fund)which has accumulated up to a given time in the life of an item. In my opinion it is not wise to generally consider a depreciation fund as related to a sinking fund in the sense of a provision for contingencies. The provision of a sinking fund proper has its own field. In this connection I gather that Mr. Floy would combine provision for depreciation and the cost of maintenance and repairs in one item of charge. I regard a depreciation charge as one of fixed annual amount, based on the assumed useful life of the property; maintenance and repairs are quite dependent on the particular service required of the plant, and the attention given in its proper care. The amount of charges for maintenance and repairs is then dependent on the operation of a plant or property in much the same way as the care of firing a boiler, for instance, will determine the fuel cost. Then is not a charge for maintenance and repairs properly an operating charge? It is admitted that in the case of an extended system with numbers of similar items, the distinction between maintenance and repair charges, and depreciation charges, may be considered of such

Digitized by Google

minor importance as to be dropped in accounting, but the principle remains, for the extended system is quite the exception to the rule.

While I agree with Mr. Floy that the application to be made of figures for depreciation charges should be known when the figures are decided upon, I feel that the underlying principles which determine the figures are definitely fixed except in very special cases. In this connection he designates certain reductions of worth as theoretical and others as absolute. If the value of a plant is to be estimated for any purpose it is only fair to consider its remaining useful life in fixing the value. The value of a property is, therefore, directly dependent upon its remaining useful life at the time. It seems to me that this proposition is no different from the purchase of a horse on the basis of age. From the financial standpoint, with proper management and accounting, the sum of plant value and the depreciation fund, at a given time, equals original investment. A going plant maintains practically constant profit earning power throughout its useful life, about as indicated by Curve 6 of the paper, dropping off slightly during the period of life owing to loss of efficiency and deterioration which cannot be removed by repair. Also, an abstract lot of plant equipment drops off in value immediately after purchase, about as shown by Curves 1 and 2 of the paper. Now as plants or other engineering works are built with the intention of their being operating business propositions over the period of their useful life at least, and as the *remaining total earning power* becomes less year by year in direct proportion to the life remaining, therefore, the value of the property must decrease uniformly throughout the period. The facts remain even though no depreciation fund is maintained, where a faulty business management fails to make provision for keeping the investment unimpaired, as in the case of many municipalities which, once the lighting or water works plant is in operation, provide appropriations sufficient to cover running expenses only, interest on the investment being usually paid from a general fund, and depreciation not at all provided for until demanded by the maturity of the bonds. When estimating the cost of production or operating expense in reporting upon a proposition, or when investigating an operating plant, charges for depreciation are uniformly distributed over the period assumed as limiting its useful life, in order that capital may be returned at the same rate that remaining total earning power decreases.

The above considerations argue for *uniform* reduction in worth as the actual depreciation of a going plant, (uniform depreciation charges, such as indicated by Curve 3, or the straight line method) and as the practical and logical method of providing a depreciation fund, as against Mr. Floy's designation theoretical to this method.

The method indicated by Curve 4 is a legitimate distortion

Digitized by Google

of Curve 3, developed by the financial consideration that all idle funds should be put out at interest. A method such as that represented by Curve 5 is a distortion of the real principles of providing for depreciation, developed for special considerations in accounting or business administration.

In considering obsolescence, any difference in value of an item, at the time of its replacement, and its salvage or scrap value, should be charged as capital added to the investment in new equipment replacing the old. If the replacement is not a good investment when burdened with this charge, it is not justified. This point is clearly expounded in a paper on industrial power costs by M. O. Jenkins of the New York Edison Company in the June 20 issue of *Power*.

I am of the opinion that any figures which might be collected for the life of plants or apparatus would be very unreliable unless accompanied by statements of the economy of the apparatus and the cost of maintenance at the time of replacement. Deferred maintenance will greatly shorten, and extended maintenance and repair will considerably lengthen the life of property and equipment. It has been my experience that industrial concerns and municipalities which do not regularly maintain technical supervision do not rightly appreciate the propriety of alterations and replacements to increase economy and better service; as long as a property runs without failure it is satisfactory, even long after its useful life has expired, as evidenced by decreased efficiency and excessive maintenance charges.

I suggest that it would be most valuable to standardize averages for economical and useful lives of various equipments and structures as indicated by the judgment of engineers of broad experience, through coöperative work by the three National Engineering Societies.

Alten S. Miller: I feel constrained to discuss Mr. Floys' paper briefly for the purpose of accentuating a few of the many good points, and for the purpose of going on record as differing from the author in certain other points. There are many important truths found in the paper they should be carefully studied and understood by every engineer who undertakes to estimate the reproduction cost and the rate of accruing depreciation of any piece of property.

Under Development Expenses, etc., it is stated: "Any one of these terms is generally used to include certain expenses, which, while a necessary part of the complete cost of a going property, are not costs inherently a part of the construction of the physical property, as such."

This statement is somewhat ambiguous. It is well known to every engineer and investor that the plant cannot be built and the property put on an earning basis without these expenses. Such being the case, they are an essential part of the cost.

In view of the general lack of understanding of this subject, it would be well if engineers would always include the overhead

Digitized by Google

charges in making statements of cost, and make a special note if they are not so included.

Under Good Will Mr. Floy states: "A monopoly, as is generally admitted, has no good will which can be evaluated." In the first place, no gas or electric light company is a monopoly. As a rule they are under different managements so that the customer may always use gas or electricity for light or power, assuming that there are no competing gas or electric companies in the territory. In addition, illuminating oil, gasolene and private power plants provide efficient sources of light and power which are sufficient to make people independent and to prevent any one company from securing a monopoly. This being the case, anyone who has managed a large gas or electric property knows that there is such a thing as Good Will and that good will has a very great value.

Mr. Floy criticizes the action of many companies in charging to capital account replacements due to obsolescence.

An examination of the electric light and street railway properties of the larger cities of the world, shows that the property has depreciated so rapidly through obsolescence that few of the companies have earned their interest and depreciation. A quotation is given from the opinion of Justice Brewer, delivered in 1904, as follows: "It is not always reasonable to cast the entire burden of the depreciation on those who have invested their money in railroads." Under many conditions the capitalizing of property that replaces other property which has become obsolete is not only not an error but is eminently proper from the point of view of the investor and the public.

Obsolescence is shown in one of two ways: Either the service is not abreast of the times and the demand, or the operating expenses are too high. Assuming that either condition has been produced by inventions subsequent to the installation of the plant and that the earnings have not been adequate to permit the investment to be written off, it is to the advantage both of the investor and the public to discard part or all of the old plant and capitalize the replacements. The public thus has increased facilities for which it is proper that the company should be compensated; or economies are realized, the advantage of which may be enjoyed by both the investor and the public.

The table given assumes that the property is profitable from the beginning, and that the company can afford to set aside $160,000 each year for interest and depreciation. In view of the fact that few if any of the public service corporations are so fortunate as to earn interest and depreciation during the first years of operation, the real course to be followed in justice to the investor and the public lies between the two plans shown in the table. The depreciation as well as other losses in the early years should be capitalized until the property is earning all expenses including depreciation and an adequate return on the investment.

The author states: "if no depreciation fund is set up, nothing

Digitized by Google

can be included in the cost of operation as necessary to provide for depreciation."

This is partly covered by my statement in the last paragraph. If a company is not earning enough to take care of its depreciation, it is, nevertheless entitled to take the accruing depreciation as a part of its cost of service in any question of rate regulation. A company is warranted in paying interest on its bonds and floating indebtedness before providing for depreciation, and in some cases it is wise to pay dividends on stock in order that additional amounts of money may be raised to develop the property, although if the full amount of depreciation were provided for, such dividends would not be earned. These questions must be settled by the managers of each property and cannot be governed by any general rules.

The author makes the statement: " From the cost should then be deducted this absolute depreciation in order to obtain the present real or service value of the property."

In determining depreciation, is it not safer to estimate the amount that will be required to put the apparatus into a condition that is practically as good as new and call that amount " depreciation " rather than to decide that the machinery is worth say 50, 60 or 70 per cent of its original cost, and to call the difference between one of those figures and the original cost the depreciation? The former is the usual process followed.

The 50 per cent method quoted in the paper is so seldom applicable that it seems hardly proper to quote it as a method having any merit. If there is a piece of property that is not growing and the maintenance of which is uniform from year to year, it is a curiosity. Certainly this method would not be applicable to a growing property or to a case wherein the methods of construction are improving as replacements are made. It is not applicable therefore to the poles, cross-arms and braces of an electric company.

Inasmuch as small transformers, meters and arc lamps have been replaced largely through obsolescence, this rule is not applicable to them. In the case of boilers it may be found that a certain percentage of tubes are replaced each year, but it will be found on inspection that a large portion or all of these tubes will be on the first and second rows, numbered from the bottom. The tubes above this may be 100 per cent efficient, and it would be a serious error therefore, to say that the tubes as a whole are only 50 per cent efficient.

In the case of a gas company the amount spent for maintenance of mains and services might be the same each year, but the depreciation will be found on examination to be due to some local condition, and a large part of the work of maintenance will be done in a few localities. The rest of the pipe system will be in condition as good as new or 100 per cent. Under these conditions it would be grossly improper to say that the distributing system as a whole is only 50 per cent efficient. On the whole it is highly

Digitized by Google

improbable that there is a single case anywhere in which such a method would be properly applicable.

It is stated: "While usually preferably there exists no necessary reason for always writing off certain costs such as engineering, incidentals, etc., at the rate at which the physical property of which they are an inherent part, is depreciated."

It is somewhat difficult to understand exactly what is meant by this paragraph. Replacements usually require engineering and when completed the cost will usually be found to contain many incidentals. In other words, these items are elements of the cost of replacements as well as of the original construction, and to this extent allowance should be made for their depreciation at the same rate as allowance is made for the depreciation of the other values of the inventory property. Such replacements will not affect the design of the property as a whole, and to this extent it is not necessary to depreciate the general engineering and incidental expenses.

In conclusion I will summarize briefly my opinion on the points in which I disagree with Mr. Floy.

Development expenses, intangible or overhead values, are an essential part of the cost of construction of physical property and should be included as such.

Electric light and power properties do not have monopolies, but may have "good will" which latter has a very real value.

It is proper in many cases where corporation earnings have not been sufficient to maintain the property, to capitalize replacements.

If the earnings of a corporation are not sufficient to set up a depreciation fund, it is nevertheless proper for purposes of rate making to include a fair estimated cost of depreciation.

The easiest and safest method of determining depreciation is by estimating the cost of putting the property in a condition substantially as good as new.

The 50 per cent method of estimating depreciation requires so many qualifications and has such a narrow application as to make it very unsafe.

The engineering costs, incidentals, etc., that would probably be involved in connection with replacements should be written off with the physical property in connection with which the expenses have been incurred.

Frank F. Fowle: Mr. Floy's paper on depreciation is notable for its careful analytical treatment of a subject that seems in danger of becoming hackneyed, but which, as he points out, needs more extensive illumination than it has yet received. An examination of the literature on the subject reveals a great mass of material which treats of life tables and associated matters, but little which is specific on the side of theoretical analysis.

The term depreciation is a generic one, meaning the "act of lessening or crying down of price or value," or "the falling of value; reduction of worth." The broad term has been loosely

Digitized by Google

employed in a great many instances with different specific meanings. There is thus great need, as Mr. Floy emphasizes, of careful qualification and definition; and in order to promote mutual understanding among engineers, lawyers, economists and accountants there ought to be established by common consent, a comprehensive and authoritative nomenclature.

In view of the great importance of the subject it is suggested that a special committee of the Institute might be appointed to formulate definitions and stimulate discussion of those phases of the matter which need it; or the Electric Lighting Committee might carry out such a program.

The common confusion between maintenance and depreciation arises, fundamentally, because there has never been devised or applied a thoroughly scientific system of depreciation accounting. It doesn't seem to me that the plan of lumping maintenance and depreciation helps the case any, because there are so many maintenance expenses that have nothing to do with depreciation and are not related in any way to the life of the plant.

In the strictest view of the matter any renewal, however trivial, ought to be charged to depreciation, but in practice it is difficult to do this and as a rule only heavy or important replacements go to depreciation. For example a life of twenty years might be assigned to a certain Corliss engine and it might turn out to be the actual life, but during that time various minor parts would wear out and be replaced, perhaps several times, and the cost charged to maintenance. The problem is to determine how far we ought to go in subdividing a property into its elements or component parts, in classifying renewals as depreciation or maintenance. Two very important purposes of a depreciation fund are to maintain undiminished assets behind the stock and bonds, as the plant wears and depreciates, and secondly to maintain an even annual charge against revenues to take care of replacements and renewals. Other purposes can be mentioned, but these are fundamental. If they are substantially met there can be no argument except over questions of a more purely technical nature.

But this involves the vital question of how property depreciates, or how fast and in what manner it passes from its value new to its scrap or salvage value, when the life is assumed or known. This question Mr. Floy discusses under the head of "absolute" and "theoretical" depreciation. The absolute depreciation of public utility property which forms part of a going concern he defines as curve No. 6 in Fig. 1 of the paper, while the theoretical depreciation might be one of the curves No. 3, No. 4 or No. 5.

There is here a marked difference between two definitions of present value, taken at any time during useful life. The theory represented by curve No. 6 is given in the paper and in substance amounts to this:—that a property which is maintained

Digitized by Google

at approximately full efficiency, without unreasonable expense, throughout its useful life, is substantially worth its cost new, or original cost, up to or very closely approaching the time of its abandonment. That is to say, it is able every day to render the same service and do the same work at undiminished efficiency. Or in other words, present value is measured by a state of readiness to serve or ability to give immediate service, without regard for the future time during which that service can be sustained. On this theory there is very little if any depreciation on a property which is reasonably well maintained.

But is this a correct economic view? We must go back to the definition of value and examine its elements, in order to arrive at any conclusion. The economic definition of value is power in exchange; utility or usefulness is one of the important elements and always present, although it does not, alone, establish value. Ely classifies the elements of value as follows.

Value { Elementary, as in raw materials. / Form, as in manufactured products. / Time, Place } created in retail trade.

In the case of a going public utility, whose business may be assumed to exist through the future years indefinitely, the element of *usefulness*, in its relation to plant value, seems to be most important. For example, such a concern could afford to pay twice as much for a generator (of a given size) which would last 30 years as it could for one which would last 15 years, assuming equal efficiency and maintenance cost. Or again, if the generator which had a 30-year life were 15 years old and in a normal condition of maintenance, the company could afford to pay as much for it as for the new generator which had a 15-year life.

Stating this principle in more general terms, the total usefulness is as much an element of value as immediate usefulness. A state of readiness to serve, without regard for the ability to render prolonged service, is not then the full measure of value; it is naturally an element of value and must be present, but after that it is remaining years of useful life which determine the plant value in a going public utility.

I have never been able to find a sound economic argument for such a theory of present value as that corresponding to curve No. 6 of Fig. 1. Total usefulness seems to me to be the great controlling element, and as that usefulness expires progressively with the rendering of service day by day, so it seems to me the value must expire also.

B. E. Sunny: Every paragraph in Mr. Byllesby's splendid paper is worthy of special notice and comment, but there are two paragraphs of paramount importance.

The first one is with reference to State Commissions.

Originally the idea of State Commissions met with great opposition among the utility companies, for the reason that they

Digitized by Google

had been accustomed to dealing with the State and local municipal authorities, and they did not know whether they would be dealt with fairly by the new body or not.

The splendid record made by the Wisconsin and other Commissions has almost entirely changed the opinion of the public and the utility people with respect to the value of Commissions, and there are few now who do not endorse the State Commission idea of municipal management.

One thing that makes it possible for the State Commissions to deal intelligently and fairly with utility companies is that they are far removed from active politics.

In the City of Chicago, the handling of telephone and gas rates by the City Council during the past two years, during which time nothing has been accomplished, has been seriously interfered with by political considerations.

As a matter of fact, the utility companies as a rule have nothing to fear from either State or City regulation, or by Commissions, inasmuch as that perhaps not more than 5 per cent of the total number are earning in excess of operating expenses a proper charge to depreciation and a fair return on the investment.

Most utility companies are for the time being content if they are able to pay 7 or 8 per cent dividends, but they have either wholly or partially overlooked depreciation and obsolescence, and are making little provision for either.

As a matter of fact, the State Commissions, made up of intelligent experienced business men and engineers, are needed for the aid and guidance in the commercial management of utility companies quite as much as they are needed to protect the public from either bad service or extortion.

The other point in Mr. Byllesby's paper is to the effect that estimates covering new construction are usually too low, and the cost of the work runs all the way from 10 per cent to 100 per cent in excess thereof. This is of course within the experience of every one engaged in construction work.

The suggestion is pertinent that in appraising plants the same percentage of error ought to be taken into account.

In a recent letting in Chicago for caissons for a new office building, six bids ran from $140,000 to $203,000 or a difference of 30 per cent.

In the building of the Sanitary District Canal, some years ago, the work was cut up into sections, and let to a dozen or more contractors. All but one of the contractors failed.

We may or may not know how the contractor comes out on the caissons at $140,000, and we may or may not know how great a loss most of the contractors made on the Sanitary District work. We are likely however to be influenced by, and to make use of corresponding figures when they are applicable for the purpose of appraising work, with the result that a serious injustice is done.

Indeed, I regard it as unsafe to permit one individual or firm employed by the municipality, to appraise a utility prop-

Digitized by Google

erty for rate making purposes, especially where. I think that in such cases, the utility company should be allowed to have an appraiser to represent its interest, and before the work is begun, the two appraisers should select an umpire to settle the differences which will inevitably arise. It is only in this way that the error to which Mr. Byllesby refers can be at least partially guarded against.

The paper by Mr. Floy is one of the best contributions to the subject of depreciation that I have seen. It brings us down to date on a vital item in the handling of a public utility.

It is significant that Mr. Floy makes no argument with reference to the existence of depreciation. This indicates progress. A dozen or fifteen years ago, there were many who did not believe that there was such a thing as depreciation. Now it is generally recognized. Even today however, depreciation has not taken its proper place in the utility accounting. In good times, depreciation receives liberal treatment out of the satisfactory earnings, while in bad times, when the earnings are scant, it is forgotten. This at least is true of the utility companies, of which as I said above, there are few that are really making any profit where proper charge to depreciation is included.

I am rather in hopes it will not be very long before the practice will become general of including a charge to depreciation with the same regularity and care that we charge to operating expense, interest and dividends, and have the fluctuation with reference to good times and bad reflected in the surplus account.

Halbert P. Gillette: Mr. Floy has presented an interesting discussion of the very important subject of depreciation, particularly from the viewpoint of the appraising engineer. Not only because the author of this paper has mentioned the writers' name in connection with the application of plant mortality tables, but because the writer may be able to add some information on the general subject of depreciation, does the writer offer a discussion of a paper read before a society in which he is not a member.

To begin with, the writer does not use the term depreciation in the sense it is used by the author. The author's use of the term makes it include both the cost of current repairs of parts of each plant unit and entire renewals of whole plant units. The writer uses depreciation to denote the cost of renewal of whole plant units only, and this, he believes, is the sense in which the term is now used by nearly all public service and railway commissions that have had to do with many appraisals of public utilities. Due to the fact that there is still no entire uniformity of practice in the use of the term depreciation, it seems desirable either to adopt the present rather general practice of using it to mean cost of renewals of plant units, or else to adopt the word amortization in its place.

A plant unit is a structure or machine which, for accounting or appraisal purposes, is regarded as a unit; as, a building, a car, a boiler, a railway cross-tie, etc.

Digitized by Google

The author proposes the expression "theoretical depreciation" to denote the cost of renewals of plant units, but the expression is too cumbersome for convenience in use.

In the second edition of his "Handbook of Cost Data," the writer called attention to the great desideratum of uniformity of practice among engineers in the use of the word depreciation. He also pointed out that while the renewal of entire plant units does not differ in principle from the renewal of parts of the same units, it is desirable to record the costs separately. Thus, the repairs of a locomotive may average 18 per cent of its first cost per annum, while the renewals of entire locomotives may average 4 per cent. The 18 per cent is a repair item, while the 4 per cent is a depreciation item, and the sum of the two, 22 per cent is the total cost of maintenance. Many engineers have made serious blunders in estimating the cost of maintenance by using published depreciation percentages under the mistaken idea that they included current repairs as well as renewals. In fact, engineering literature is replete with examples of just such blunders.

Shall depreciation be deducted from the cost of reproduction new to obtain a plant value that shall be used as a basis for rate making? This is an ever recurring question, and one that grows daily in importance. The writer's own answer has been that depreciation shall be deducted from the new value, but that it must usually be added on again in the form of development expense. The writer uses the term development expense in a sense different from that used by the author of this paper. The writer's definition is:

Development expense is the accumulated deficit in fair return, from the start of operation of a plant until a fair return begins to be earned.

There are some appraising engineers who call this the "going value" instead of development expense, but the term "going value" means so many different things to different men that it is not a desirable term to use.

As an example of the method of calculating development expense, Tables I and II will serve. Table I is based on the assumption that no depreciation has occurred. Table II is based on the assumption that there has been depreciation.

Table I gives an example of a plant assumed to cost $100,000 and to begin operating January 1, 1900. For the sake of simplicity it is assumed that there have been no additions to the original plant. To begin with, assume that there has been no depreciation, and assume that 8 per cent is a "fair return". Then we have the results shown in Table I.

The deficits, column (5) of each year are the development expense of that year, and the total development expense is $5,144, so that at the end of the development period, December 31, 1904, the total value of the property is the cost of the plant, $100,000, plus the development expense, $5,144, or a total of $105,144.

Digitized by Google

TABLE I

(1) Year	(2) Value Jan. 1	(3) Fair return at 8%	(4) Net earnings from operation	(5) Deficit	(6) Value Dec. 31
1900	$100,000	$8,000	$6,000	$2,000	$102,000
1901	102,000	8,160	6,500	1,660	103,660
1902	103,660	8,293	7,200	1,033	104,753
1903	104,753	8,380	8,000	380	105,133
1904	105,133	8,411	8,400	11	105,144
				$5,144	

Now let us assume that there has been an actual depreciation of $15,000 in the plant value, as disclosed by an appraisal. Then from the actual net earnings should be subtracted such a sum annually as to provide (at 8 per cent fair return) an amount equal to $15,000 at the end of the year 1904. This would be $2,556 deducted annually from the net earnings shown on the books. Table II gives the result of the calculation on this basis.

TABLE II

(1) Year	(2) Value Jan. 1	(3) Fair return at 8%	(4) Net earnings	(5) Sinking fund	(6) Deficit	(7) Value Dec. 31
1900	$100,000	$8,000	$6,000	$2,556	$4,556	$104,556
1901	104,556	8,364	6,500	2,556	4,420	108,976
1902	108,976	8,718	7,200	2,556	4,074	113,050
1903	113,050	9,044	8,000	2,556	3,600	116,650
1904	116,650	9,333	8,400	2,556	3,489	120,139
Total					$20,139	

Table II shows that the total deficit, or development expense, is $20,139 based on the assumption of depreciation, which if added to the depreciated value of $85,000 gives a total of $105,139

Contrasting the results of the methods derived from Tables I and II, we have:

	Table I	Table II
Plant value	$100,000 (new)	$ 85,000 (depreciated)
Development expense	5,144	20,139
Total value	$105,144	$105,139

Had the calculations been carried out to one or more decimal places, the final results would have been identical. We see from this illustration that the development expense calculated on the

Digitized by Google

assumption that the plant has depreciated exceeds the development expense calculated on the assumption of no depreciation, and that this excess is precisely equal to the amount of the depreciation that has occurred during the development period.

There is very much more to the subject of development expense than is likely to occur to one who has not applied it in many cases, but it would lead to such a digression from the subject of depreciation that the writer can not touch upon it further than to point out how it serves to solve the problem of giving justice to a public service corporation that has not provided a sinking fund with which to wipe out the depreciation that an appraisal may show.

Rarely has any large corporation, public or private, provided a depreciation fund with which to recover any considerable part of the loss in plant value due to depreciation. What rational appraising engineer or public service commissioner would contend that a sinking fund should have been established to provide for the loss of value of cross-ties in a railway track? Cross-ties in a track, if properly maintained, ultimately attain an average value of about 50 per cent of their cost new; but who will urge that a sinking fund should be established to provide for a 50 per cent lost value, when the " service value " of the ties is as great at any time as on the day they were first laid? Obviously no one would so contend, unless it were proposed to sell the railway as one would sell a second hand machine, which is a thing that neither the railway owner nor the public contemplates. What holds true of cross-ties holds true of many other plant units. In any event, the writer's method of calculating development expense (as indicated in Tables I and II) shows clearly that if the public intends to be just in its treatment of public service corporations, it must either regard the plant as being worth its actual new cost, or it must permit the corporation to revise its old operating accounts, from the day the plant began operation, so as to include an annual allowance for depreciation, which shall fully cover the past depreciation disclosed by a present day appraisal. This is but common justice, and, when such justice is measured out, it results inevitably in an increase of the development expense by an amount equal to the depreciation, as above shown.

The writer may add that he believes there is a startling surprise in store for the public—a public that has been woefully misled by recent articles in popular magazines as to the extortionate profits made by railways and other public utility corporations. The writer's appraisal of the railways of Washington made it clear that in that state the railways were not robbing the people, and were, in fact, averaging a return that no merchant, manufacturer, or farmer would be contented with.

The writer has recently been engaged on the appraisals of five street railway and interurban electric railway systems, not one of which shows a return on the investment that would

Digitized by Google

satisfy the business men of the communities in which they exist; in fact, the accumulated deficit in fair return, assuming as low as 7 per cent for a fair return rate, has been more than 40 per cent of the aggregate cost of the physical property of these electric railway plants, in spite of the fact that the plants (with one exception) have been long established and are in growing communities. In other words, the development expense of these five electric railway systems has been more than 40 per cent of their first cost, and is not ended yet. Moreover—and this is a matter of extreme importance—this 40 per cent development expense is calculated on the assumption that there has been no depreciation; but, with an adjustment of the accounting records to include depreciation (amortization) as a part of the operating expense, the percentage for development expense becomes much greater.

The writer has observed with growing interest that other appraisals of electric railways all point toward the conclusion that that railway is fortunate indeed that can develop a sufficient business to yield a fair return on the cost of the physical property without incurring a development expense (a going value expense) of at least 30 per cent of the cost of its physical property new. And, if, as seems likely, the average depreciation of all electric railways is about 20 per cent, as determined by appraisal on the straight line theory, then the development expense will average about 50 per cent of the cost new, which is to be added to the depreciated plant value to obtain the total value of the plant and its going business. No man can say exactly what the average percentage will ultimately be found to be, but it is evident that not merely the public but experienced engineers will be surprised by the facts that are now in process of disclosure as a result of numerous electric railway appraisals.

The author of this paper gives a table of rates of depreciation used by different appraisers, and he speaks of them as having, in effect, "largely become law".This is apt to be misleading, for, of course, the use of a rate of depreciation by no appraiser gives it even the semblance of law, nor does the acceptance of an appraiser's estimate by a public service commission add much to the credence that engineers or court should necessarily give to the truth of the figures.

Many of the rates of depreciation given in the author's table are rates based upon engineering guesses as to the life of machinery, and the life is a life determined by obsolescence or inadequacy.

The writer found that the life of locomotives and cars used by several large railway systems had averaged 28 years. It is quite generally known that many locomotives are in use on European railways after a life of more than half a century, showing that depreciation of locomotives in America has been almost entirely a matter of economic inadequacy. Locomotives are quite typical of other machines. With the exception of a few plant

Digitized by Google

items that depreciate by rotting, such as wooden cross-ties and poles, and a few items that depreciate by abrasion, such as rails, trolley wire and pavements, there are scarcely any items given in the author's table that have a depreciation rate that has not been estimated on the basis of life lost through obsolescence or inadequacy. This being so, it becomes illogical to attempt to appraise the depreciation of many items of a public utility by mere inspection. The writer believes he was among the first, if not the first, to take cognizance of this point in making an appraisal of great magnitude. At least the writer was the first engineer of a public utility commission to abandon entirely any attempt at inspecting all the property of public utilities to determine the depreciation. The writer prepared plant mortality tables of all classes of plant units, and from the age of the plant units deduced the depreciation. A description of the method and discussion of the reasons for its use are given on page 1295 et. seq. of the writer's "Handbook of Cost Data.

The author is wrong in his statement that the writer used what the author calls the "fifty per cent method of depreciation." What the writer did do was to call attention to the fact that all depreciable plant, where there are numerous plant units, ultimately depreciates 50 per cent of its wearing value if the plant is properly maintained; and, in the absence of any knowledge whatsoever as to the average age of plant units, it would be reasonable to use the "fifty per cent method" where inspection of plant units indicates that the "fifty per cent method" would yield approximately correct results.

If wooden cross-ties, for example, have been so long in use as to attain a rate of renewal equal to the reciprocal of their total life in years, then it amounts almost to a certainty that their average depreciation is 50 per cent, by the straight line formula. However, even in the case of ties, the writer has seldom been forced to guess, but has found it possible to deduce the average life either from the accounting records or from the engineering records.

As for inspection of such plant units as wooden ties or poles to determine depreciation, the writer can find little good reason, No man can look at the average tie or pole in use and tell its probable remaining life within a wide margin of the truth. A far closer estimate can be made if the average age is known.

Field inspection of wear of rails, trolley wire, etc., is more satisfactory, but even that can often be largely eliminated. Thus, for rails or trolley wire, careful measurements of wear due to a known number of cars will disclose the rate of wear; and from such data can be calculated the probable future life of other rails or trolley wire if the average density of traffic is known. But the life of rails is not always a function of the rate of wear, so that neither inspection nor calculation based on wear measurements will always disclose the true depreciation. Increased weight of rolling stock has been a most potent factor

Digitized by Google

in causing rail renewals in the past, for rails have become inadequate because of the greater wheel loads they have been required to support. Nor is this all. Just as one change in chemical composition of rails led to the replacement of iron by steel, so other changes are now causing replacement of common steel by steel alloyed with ferrotitanium and other metals.

View the whole subject as we may, we are driven inevitably to the conclusion that inspection is apt to be a very misleading method of determining depreciation for almost any kind of plant unit, and that for most kinds of plant units inspection is the most misleading method that can possibly be used. No amount of inspection can show the rate of depreciation due to obsolescence or inadequacy.

A very strong argument can be made in behalf of estimating depreciation solely on the rate of loss of life due to wear, tear and disintegration by natural forces. While this method is seemingly to be desired by public service corporations whose property is being appraised for purposes of rate making, it proves to be a boomerang the moment consideration of the maintenance expense begins, for then a corporation naturally and rightly wants to be permitted to take out of earnings enough to provide for depreciation due to obsolescence and inadequacy.

The writer believes that no man can accurately estimate *future* depreciation due to obsolescence or inadequacy, but the only safe and fair way is to base future estimates of depreciation on past experience. Then the rates of depreciation thus deduced should be applied both in appraising depreciated values and in providing sinking funds or depreciation reserves out of earnings. It may be demonstrated mathematically that a public service corporation, the weighted age of whose depreciable plant is less than $\frac{1}{R}$, is the gainer the higher the rate of depreciation assigned to the plant, R being the rate of fair return. Thus, if the rate of fair return R, is 8 per cent (0.08) we have $1 \div 0.08 = 12\frac{1}{2}$ years as the critical age. If the weighted age of the plant is less than $12\frac{1}{2}$ years, then the more the estimated depreciation rate exceeds what it actually should be, the greater is the corporation the gainer by the error, provided the same rate of depreciation is used in estimating allowable amounts for sinking fund deposits.

This formula $N = \frac{1}{R}$ for ascertaining the critical age can readily be proved true by the application of algebra, or by taking a few specific numerical examples.

Nearly all public service corporations, and steam railway companies in particular, have failed in the proper presentation of their cases to commissions and courts. This has been due to their ignorance of the problems of appraisal and rate making. They have fancied that their own operating engineers, officials

Digitized by Google

and attorneys could readily prepare both the data and the arguments. Never was a more serious blunder made. Their engineers have usually not deeply studied either appraisals or rate making, and their lawyers have usually understood neither end of the problem. Finally, railway commissions themselves have often erred, because, while they have regarded appraising as being an engineering problem, they have not always regarded rate making as also involving equally important engineering problems.

Depreciation, as we have seen, affects not merely the problem of appraisal, but it gravely affects the matter of estimating operating expenses. The operating expenses of any single year are usually not typical, that is, they may be either higher or lower than an average over a long term of years, due to variations in the cost of renewals of plant units—*i.e.*, depreciation costs. When a plant is young its current repairs are smaller than they will be later on, and renewals (depreciation costs) are usually absent entirely in a young plant. It is an engineering problem, therefore, to determine what the maintenance expenses are going to be, and therefore it is an engineering problem to estimate proper allowances for maintenance during a typical or average year. No other kind of a year can be justly used as a basis for rate making. This is not the only reason why rate making is largely an engineering problem, but, even if it were, it would be sufficient reason why expert appraising engineers are needed not only in making appraisals of existing property but in appraising maintenance expenses.

Railway corporations have usually failed to secure an adequate allowance for "going value" or development expense. Most of them have secured no allowance at all, entirely because they have made no careful study of appraisal problems. They have often lost their development expense and with it has gone also that part of the development expense due to depreciation. They have known intuitively that they were being deprived of their rights under the guise of law, but they have not been able to give adequate reasoning for their belief in the injustice they were suffering. Driven to extremes they have often lied about the value of their physical assets, when they could have secured all that they were fighting for in the way of total values by merely proving their development expense from their own accounting records.

Recently the Wisconsin Railroad Commission has adopted a modified form of the above described deficit method of calculating development expense, and the commission has ruled that in calculating development expense the old operating costs of a company must be increased by a sufficient sum to cover the actual depreciation. This is one of the most important steps ever made by a public utility commission, and probably marks the beginning of the general adoption of a wholly rational method of ascertaining that hitherto elusive element of cost—development expense or "going value".

Whether past depreciation should be amortized from future

Digitized by Google

earnings or not is largely a matter of sentiment. In fact, whether development expense (going value) should be amortized or not is also a matter of sentiment. It probably will make little difference either to the public or to the public service corporations what procedure is adopted, for whether development expense remains as a source of revenue to a company or whether it is amortized, the company will get its *quid pro quo*.

Henry Floy: The rather close connection and joint discussion of Mr. Byllesby's and the author's paper, sometimes makes it difficult to analyze and reply to certain of the speakers' arguments.

The careful and lengthy discussions of the paper under consideration, by men of such prominence as those who have contributed, indicate the wide-spread interest and importance of the subject; at the same time clearly substantiating the authors opinion that there exists a notable lack of uniformity of nomenclature and a wide diversity of opinion in matters relative to "Depreciation."

The author appreciates the efforts of several of the contributors in their attempts to clarify and properly define terms. This would be more acceptable were it free from a spirit of sarcasm apparent in the discussion of one participant, but so out of place before an engineering society. Aside from any attempted definitions which may be purely academic or put forth as a species of mental gymnastics, most engineers agree with the author that utility has a value which may be expressed in dollars. If not, the values indicated by the curves Nos. 3, 4 and 5, in Fig. 1, may not be expressed in dollars any more than curve 6, and the only value that may be attached to the property being appraised, if the term relates exclusively to barter and sale, is the second-hand or scrap value, which all informed engineers will agree is not the basis on which any appraisal has been or is being made for determining the physical values of an operating concern. Because John Stuart Mill years ago, or other political economists, once attached a certain meaning to the word "value" does not signify anything with regard to the present use of the noun. Words change their meaning daily, and the word "value" may properly be used to measure utility, the original value of which has perhaps been determined through purchase.

As has been suggested by several speakers, the Institute could appropriately take under consideration the proper definition of terms used in connection with the subject of "Depreciation," coöperating with the other national societies in this matter. The National Electric Light Association has already a committee at work on this subject.

Several prominent engineers indicate that in their opinion, for rate making purposes, certainly, the basis for valuation is the cost of the physical property reproduced as new, plus certain development expenses. This is a very satisfactory showing and indicates decided progress. Mr. Arnold explains and

Digitized by Google

accepts this basis frankly, while Mr. Gillette comes to the same conclusion through the inclusion of what he unfortunately terms "development expense." His application of this term to what has generally become to be known as "going value" and has been so used for years by the Wisconsin Commission, will hardly be accepted by informed engineers. Mr. Gillette himself seems to find it necessary to use "going value" to explain what he improperly calls "development expense". It would seem as if those who differ from the author in the use of terms or definitions set out by him, should advance sound argument for substitution of terms they propose rather than mere expression of preference, or what they have been accustomed to do as against the wider use and more general custom, which the author has attempted to follow.

As stated by the author, the tables showing accepted rates of depreciation, which include as a rule some allowance for obsolescence and inadequacy, cannot be applied indiscriminately, and must be used conservatively. They are given as indications of what has been done; in fact much of the entire paper has been written to show the line of procedure heretofore followed. It would seem that we can only advance by a thorough understanding and knowledge of what other people are doing in treatment of the subject of depreciation, and these tables are given because they show figures which have been approved in important cases, and what fairly may be expected by those who are interested in operating companies when they have to appear before commissions or courts. The readjustment of rates based on the use of such figures and their acceptance both by the Public Service Commissions and public utility companies, certainly establishes them much more firmly than mere engineer's opinions, and gives them in effect the semblance of law.

Considerable of the discussion apparently relates to methods of procedure applicable to newly organized or recently started companies, where either the application or omission of theoretical depreciation can be, made without injury to the interests of those who have invested their money. This condition, however, does not apply to old corporations and it is unfair to take advantage of those who have already invested their money, and are unable to take it out, to apply too strictly rules such as those covering theoretical depreciation, where such application will result in the confiscation of property running into perhaps millions of dollars. This is evidenced for example, in the case of some engineers who, while claiming that curves Nos, 3, 4 or 5 Fig. 1, are those to be used in determining the present value of property, are very careful to avoid trying to demonstrate the absolute accuracy of any one of the three curves, although the use of one or the other would result in a difference of several millions of dollars, as has been shown for example, in the valuation of street railway properties in New York City. The use of one curve or the other, admittedly, is largely one of preference or convenience, and being based on an

Digitized by Google

assumed theoretical life always results in discussion in the endeavor to prove the truth of the assumption, which is not absolute.

Several of the speakers apparently failed to grasp the author's distinction between "absolute" and "theoretical" depreciation, and the fact that these are *both* considered in determining present value only, that "theoretical" depreciation alone is used in determining annual rates of exhaustion of life. Mr. Hoxie seems unable to appreciate that a yearly rate of depreciation has nothing whatever to do with the total absolute depreciation, and his illustrations as to rulings of Commissions, assume an ignorant commission unable to revise its rulings, as it finds the amounts laid aside for depreciation are larger than required. Further, he seems unacquainted with the very wide practice of corporations and the rulings of at least one Public Service Commission, practically prohibiting the building of extensions out of excess earnings, which many consider contrary to the best policies now in vogue. Of course the author was endeavoring to cover the usual case that exists and not the exceptional, covered by the illustration. The author has not conceived of "two separate rates of depreciation" applied to the same property, nor does he agree that the appraisal must include a deliberate judgment of the value of useful service remaining as it is present service, not future service, which the public is interested in, and upon which the rate of return must be based. In the Consolidated Gas case, the Supreme Court did not tell us to figure two kinds of depreciation. It did tell us to figure one kind of depreciation, and that is what the author has called "absolute" depreciation, which is to be used in determining the present value, on which rates are based. It did tell us that no "theoretical" depreciation should be deducted in establishing the basis on which to estimate fair return. In the Knoxville Water case, the Court clearly states that the original investment, regardless of "absolute" depreciation, is not the basis for figuring a fair return, and furthermore that proper allowance, as a part of operating expenses, should be made to cover the wasting away of physical property. Mr. Hoxie evidently agrees with the engineer of the Public Service Commission, that it is a very easy matter to appraise the Third Avenue R.R. by the "50 per cent method", which basis the Public Service Commission accepted in part, and obtained a depreciated value which does not compare with the value or appearance of the property to anyone who knows it, and demonstrates as well as anything can that "theoretical" depreciation is purely theoretical.

Mr. Foster states that "repairs are continually made in the endeavor to keep the property up as near its original value as possible". This is evidently an over sight by Mr. Foster, as of course he recognizes that repairs are made not for the purpose of keeping property up towards its original value, but to maintain it in good, operating order. He is also mistaken in stating that "It is utterly impossible that taking at any moment the

Digitized by Google

value of the whole property could be 100 per cent of its original value " as it can be easily recognized that a sudden rise in the value of real estate of a marked difference in the price of labor and material could easily result in showing by appraisal, the value of the property at 110 or more per cent of its original cost. In fact the values of 75 per cent or 85 per cent so frequently used as that of property in good condition depends on how much of the physical property is of long life, or whether the relative amount of total investment is largely in real estate or road-bed, which increases rather than decreases in value with age.

With regard to the Springfield Street Railways, the author entirely agrees with Mr. Foster that the investment in horse properties should have been amortized out of earnings, if the latter was sufficiently large to permit such amortization, otherwise the value of the horse railways must be left in the capitalization, as indicated in the paper under " Total Depreciation " for example, although nothing of the original physical property remains for identification.

Of course ordinary wear and tear maintenance, renewals, replacements, obsolescence, inadequacy, must be taken care of eventually as a part of operating expenses, and paid for by the public; there can be no question on that point if investors are still to be found willing to put their money in public utility properties.

At first thought and superficially, it would seem that the sum of the plant value (the present value determined by appraisal) and the depreciation fund (where one is necessary) should, at a given time, equal the original investment. As a property kept in good operating condition will ordinarily not be found to be in a condition below 75-85 per cent of cost of reproduction, a fund larger than 15-20 per cent would never be required even on the theoretical basis proposed by some engineers, and as a practicable matter, a sum equal to 3-5 per cent of the original value, would ordinarily be amply sufficient for a property uniformly maintained.

The ambiguity, if such exists, which Mr. Miller seems to find with regard to the author's separation of development expense from physical values, doubtless arises from the attempt to include with the physical values, those percentage items which are practically fixed and uniform in all cases, such as engineering expense, allowance for incidentals, omissions, etc., and to put in a separate class under the head of development expense, those items which vary widely with local conditions, and individual management. There certainly was no suggestion that development expenses were any less a necessary part of the total outlay required than were the physical costs, but the engineering expense for example is practically always 5 per cent, while the costs of obtaining a franchise or the legal expenses, must be figured for the actual case under consideration and vary widely. It would hardly seem fair in view of the statement made in the paper under " Total Depreciation ", to state that

Digitized by Google

the author criticizes the action of companies in charging to capital account replacement due to obsolescence. This is only so in case the earnings have been sufficient to write off the obsolescence Mr. Miller says "Depreciation, as well as other loses in early years should be capitalized until the property is earning all expenses." Certainly the Public Service Commissions and engineers generally will not agree with this statement unqualified, as it would mean that poorly managed or evidently ill advised investments should be allowed to continue capitalizing losses indefinitely. There must be some limit to the capitalization of these early losses, and while a legitimate and reasonable amount may be capitalized if the earnings are too small to cover the depreciation and obsolescence, such procedure comes close to encroaching on dangerous and unstable ground. It would be interesting for Mr. Miller to cite cases in which depreciation has been determined by estimating the amount "required to put the apparatus in a condition that is practically as good as new" for certainly it is not "the usual process."

The advance copies contained some typographical errors so that the clause quoted by Mr. Miller is not clear; it should have read "while usually preferable, there exists no necessary reason for always writing off certain costs, such as engineering, incidentals, etc." the author's view being apparently in accord with Mr. Miller's, namely that original engineering expense need not necessarily be written off with the depreciation of the physical property which may be renewed without such engineering expense. For example the renewal of rails in track would be done by the operating force without any special engineering expense; therefore the original engineering cost remains in the property, regardless of the physical condition of the rails. Practically the same method of determining going value, (called "development expense" by Mr. Gillette, and shown in his tables 1 and 2) has been recognized and used by the Railroad Commission of Wisconsin for some years. It has strong claims for consideration, and if judiciously used, is applicable in many cases. Mr. Gillette truly states that no amount of inspection can show the rate of depreciation due to obsolescence or inadequacy, but neither can theorizing determine the rate. If Mr. Gillette proposes to determine all depreciation from records and computations made in an office, it would seem as if his results were entirely theoretical and hypothetical. As it is practically impossible for any engineer to determine the amount of "theoretical" depreciation from an inspection of apparatus, does not the whole question of such depreciation, which must be based on examination of records as to dates of purchase, with an assumption as to probable life, result only in speculative values; which while possibly of service in determining the price for bargain and sale, has nothing whatever to do with the value on which capitalization should be based or rates fixed, provided an inspection proves the property is well maintained.

Digitized by Google

DISCUSSION ON "WAVE SHAPE OF CURRENTS IN AN INDIVIDUAL ROTOR CONDUCTOR OF A SINGLE-PHASE INDUCTION MOTOR." CHICAGO, JUNE 30, 1911. (SEE PROCEEDINGS FOR JUNE, 1911.)

(Subject to final revision for the Transactions)

Theodore Hoock: Mr. Weichsel's interesting, theoretical investigation of the wave shape of currents in a single-phase rotor has been made under ideal conditions, *i.e.*, it has been assumed a machine without leakage and rotor resistance so that the rotor exciting current is equal to the stator exciting current, or in other words that the no load current with short circuited rotor is twice the no-load current with rotor winding open. The actual measured values, however, are smaller than those in the ideal motor, varying between 1.60 to 1.95. The reactance, and especially the rotor resistance has a vital influence upon the secondary exciting current, reducing it as low as 60 per cent of its theoretical value. The derived equations in Mr. Weichsel's paper should, therefore, be corrected in figuring the actual amplitude of the current. Bearing this in mind it may be found valuable to apply the equations in investigating local fields, which are set by the rotor currents under certain conditions, and which cause sometimes very inconvenient phenomena in the machine.

A. S. McAllister: The author makes mention of what he calls the "Fynn method" of treating alternating-current problems on a basis similar to those of the direct-current motor. Just what he intends to cover by the expression "Fynn method" is not clear, but since he contrasts it with the Ferraris method of resolving the single-phase field into two fields rotating in opposite directions, it is probable that he means the resolution of the field in the single-phase induction motor into two components in space and in (approximate) time quadrature. Although this method has been employed in the recent publications of Mr. Fynn, it seems improper to attribute to him credit for originating this method which has long been in use, and was employed by others in publications antedating the descriptions by Mr. Fynn. An early treatment relating to this method, and possibly the first to be published in this country, appeared in the *American Electrician*, in June, 1902, where the qualitative relations were accurately presented.

If by the "Fynn method" the author means the (imaginary) separation of the secondary rotor winding into two stationary circuits in electrical line with, and in electrical space-quadrature to, the primary exciting winding on the stator, as indicated in his Fig. 16, then it seems proper to state that this method was used by Professor W. S. Franklin in a paper presented before the American Institute of Electrical Engineers in May, 1904, as a reference to the TRANSACTIONS for 1904, page 429 will show. This method has been used by Mr. Fynn also, but the records available to the present writer do not disclose such use by him at a date earlier than May 1904. Incidentally, it might be noted that this method, as actually used by Mr. Fynn, would

Digitized by Google

indicate a commutated current in the individual rotor conductors and hence would not represent the facts which Mr. Weichsel discusses unless so modified as to be identical with the method described in the *American Electrician* in June 1902.

If by the " Fynn method " the author means the determination of the quantitative relations between the currents existing in secondary rotor circuits of the machine known in this country as the single-phase induction motor (that is to say, the machine operating under load without a commutator), attention should be called to certain matters on record. Records that are easily available prove conclusively that previous to September 28, 1906, Mr. Fynn had not developed any method whatsoever for accurately representing the relations existing between the currents in the secondary rotor conductors of the single-phase induction motor, because on that date he denied the existence of the relations which are recognized at the present date as being fundamental, and which Mr. Weichsel discusses in the present paper. The following quotation from a communication by Mr. Fynn in the (London) *Electrician*, September 28, 1906, will make this statement clear:

" This amounts to saying that the magnetizing current of a self-excited, single phase shunt induction motor will be equal to twice the magnetizing current required for the transformer field only, or to twice the magnetizing current which is taken by the motor when standing still with the rotor on open circuit. I have stated before, and I repeat now, that no such relation exists between the exciting current in the rotor, responsible for the motor field, and the exciting current in the stator winding and responsible for the transformer field; the former is not represented in the stator winding, accurately or otherwise."

This communication was submitted in criticism of an article which appeared originally in the *Electrical World* on August 18, 1906, which article contained a thoroughly accurate presentation of the facts now discussed by Mr. Weichsel. It seems strange indeed that this author should have singled out for credit in connection with his paper on current relation the one writer who has taken pains to deny in print the existence of the fundamental relations between the currents after they had been correctly treated by others.

To just whom credit belongs for first proposing the methods employed by Mr. Weichsel, it would be very difficult to determine, but the facts should not be ignored that such credit should not be given to a person merely because he has used such methods, and that the pages of the TRANSACTIONS and PROCEEDINGS should be free from artificial credit created in this manner.

In submitting these criticisms the present writer wishes merely to insure that credit for priority is not improperly bestowed upon any one. He has no desire to claim credit for himself or to detract from the credit properly belonging to any person. He

Digitized by Google

questions neither the sincerity of Mr. Weichsel nor the originality of Mr. Fynn, who, in fact, has made many important contributions to the literature relating to alternating-current motors.

H. Weichsel: Referring to Mr. Hoock's discussion, I agree that on actual single-phase motors, we find the no-load current less than twice the magnetizing current. The factor 2 is only a theoretical conclusion, and in the actual machines the total no load current is usually about 1.6 to 1.9 times the magnetizing current, and this deviation from the factor 2 is caused by two factors, namely the ohmic resistance and, the inertia of the rotor.

The relation between no-load current and magnetizing current is shown graphically in diagram Fig. 1, which is based on the assumption that the rotor runs exactly at synchronisms and with uniform speed.

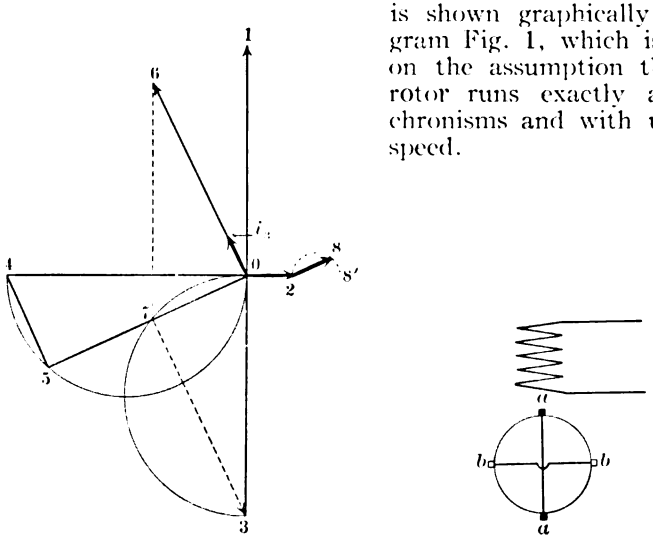


FIG. 1

0-1 = e.m.f. impressed on stator winding, whose ohmic resistance has been neglected.
0-2 = magnetizing current corresponding to e.m.f. 0-1.
0-3 = e.m.f. of transformation in *a-a* axis of rotor.
0-4 = e.m.f. of rotation generated in *b-b* axis of rotor due to rotation in main transformer field.
0-i_3 = rotor magnetizing current in *b-b* axis.
4-5 = is therefore the ohmic drop due to i_3 in *b-b* axis. It is self-evident that 5 lies on a circle over 0-4.
0-6 = e.m.f. of rotation generated in *a-a* axis by rotation in field produced by current i_3.
0-7 = resultant e.m.f. in *a-a* axis = resultant of 0-6 and 0-3. This resultant e.m.f. must be equal to the ohmic drop in axis *a-a* and is therefor proportional to the rotor current in axis *a-a*.

Digitized by Google

2-8 = primary current counter-balancing the rotor current 0-7. It will be seen that vector 0-6 equals 7-3 and as 0-6 is proportional to $0\ i_3$ and $0\ i_3$ proportional to 4-5 it follows that also point 7 lies on a circle over 0-3. But 0-7 is proportional to the resultant rotor current in axis *a*-*a* and which current must be counter-balanced by the stator current 2-8. The end of this vector must lie therefor on a circle. For the ideal case, that rotor has no resistance, the panel 8 moves to 8′ and the total stator current is 0-8″ or 2 times the magnetizing current. For a finite rotor resistance the stator current is 0-8 which according to diagram must be smaller than 0-8′ or less than 2 times the magnetizing current.

Digitized by Google

DISCUSSION ON "MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES." CHICAGO, JUNE 28, 1911. (SEE PROCEEDINGS FOR MAY, 1911.)

(Subject to final revision for the Transactions.)

Frank B. Jewett: The phenomena which underlie what seem at the present time, to be the most promising lines of investigation for the development of wireless telephony, namely, the utilization of one very high-frequency alternating current as what might be termed the "carrier" for other and lower frequency alternating currents, appeal to the imagination not only of the engineer but also of the physicist. It was consequently with more than usual interest that I commenced an investigation of Major Squier's work in the early part of this year at the time the newspapers first announced the issuance of his patents and described in a general way the character of his discoveries.

My investigation had for its object the determination of whether any of Major Squier's reported discoveries contained the germ of a speech transmission system that could be made commercially applicable in a general, universal telephone system. There were two main questions to be answered, first, were the newspaper accounts of Major Squier's work correct as to what he had accomplished, that is, was it possible even on a single circuit to obtain the results claimed? Second, on the basis of an affirmative answer to the first query was there anything in Major Squier's research that would make his discoveries commercially applicable to either a local or long distance telephone plant? If not, did the research give promise of ultimate commercial adaptation and what further developments, would be needed to so adapt it?

I think that Major Squier's paper as presented at this Convention will remove any doubts as to the first of the above queries. Major Squier's paper indicates very clearly that what has been accomplished in wireless telephony, namely, the transmission of intelligible speech by means of a high frequency alternating current carrier, can also be accomplished on a simple telephone circuit consisting of wires, either metallic or grounded, by the same or similar means and apparatus. This being so, we come at once to the second query, namely, that relating to the practical utility of the work in a commercial telephone installation. As yet I have not been able to determine that the research, beautiful though it may be from a physical standpoint, possess any great commercial value or possibilities.

In studying this phase of the matter, it is necessary to take account of all the factors which enter into the design and maintenance of circuits and equipment needed to afford commercial service. In a general telephone plant, the first essential is, a sufficient amount of energy, closely approximating the form in which it was put on the line at the beginning of the circuit, should be transmitted and delivered at the instrument of the receiving subscriber; it is also essential that this be accomplished

Digitized by Google

in such a way and by such means that the plant has a maximum flexibility of operation. Further, from a commercial and operating standpoint it is essential that the circuits used for the transmission of speech be of such a character that the necessary signaling current can be transmitted and that signaling means be provided which will give the operators immediate and complete control of the circuit. While it is not always necessary to transmit the signaling current over the same wires that are used for talking, these currents are usually so transmitted and in any plant for general telephony and telegraphy, where the wires are used to proper efficiency combined talking and signaling currents will in general be found on all wires.

In the matter of the necessary energy to be supplied, a very rapid and cursory examination of the conditions which must be fulfilled in a commercial plant, especially in a long distance telephone plant will indicate that the general characteristics to be taken account of in considering high-frequency transmission analogous to that suggested by Major Squier are not nearly as simple as on the short circuit which he used between the War Department and the Bureau of Standards in Washington and which, under the circumstances, we might term a laboratory circuit. Further, a few simple computations will show that the attenuation of current at the high frequency which must be used in Major Squier's system is enormously greater than the attenuation at the frequencies which go to make up ordinary speech. The phenomena of current attenuation on long telephone circuits are not different in character for frequencies of from 15,000 to 100,000 periods per sec. than for frequencies of from 200 or 300 to 3,000 periods per sec. and the same attenuation formulæ can be used. In rough computation work it is customary for telephone engineers to take a single frequency as designating the average of what takes place in the transmission of speech. The generally accepted single frequency for computation work is 800 periods per sec. Major Squier mentions, as the range of frequencies which are applicable to his adaptation of wireless methods to wire telephony a range from about 15,000 to about 100,000 periods per sec., the lower limit being set by considerations of audibility and by the upper or higher harmonics in ordinary speech and being quite definite. The upper limit is set primarily by considerations of current attenuation and is not quite as definitely marked.

As an illustration of the great difference in attenuation between these high frequency currents and the currents which go to make up ordinary speech transmission, let us consider what will happen on some of the open wire and cable circuits that are ordinarily used in long distance telephony—as examples of these circuits, I have taken first a No. 8 B. W. G. copper circuit, which is the largest copper wire used in commercial telephony in America; second a No. 12 N. B. S. G. copper circuit, which is the size of wire ordinarily used for rather short toll work and

Digitized by Google

third a No. 13 B. & S. gauge cable circuit, which is about the largest size copper wire circuit generally used in underground telephone cables. Comparing the attenuation of the current at the very high frequencies needed in Major Squier's arrangement to the attenuation at 800 frequency, we find the following:

At 15,000 frequency, which is the lowest frequency Major Squier suggests, the attenuation constant on the No. 8 gauge circuit is 2.2 that at 800 frequency. This ratio increases to 5.4 at 100,000 frequency. On the No. 12 gauge circuit the ratio of high frequency to 800 frequency attenuation constants ranges from 1.6 at 15,000 to 3.5 at 100,000 frequency, while on the No. 13 gauge cable circuit the range is from 1.9 to 4.2 for the corresponding frequencies.

Although the above figures indicate a markedly more rapid attenuation for frequencies above 15,000 than for frequencies in the neighborhood of 1000, they do not show in the most striking manner the serious way in which this rapid attenuation limits the commercial application of any high frequency carrier scheme of telephony. As noted before, it is necessary in a commercial telephone plant to deliver to the subscriber at the distant end of the line a sufficient amount of energy with approximately the form of the current at the sending end to give him an audible amount of sound from his receiver. If we take as a basis of our comparison the amount of energy, which at 800 frequency represents the commercial limit of telephone transmission and assume that at the receiving end of a circuit operated on Major Squier's principle, the amount of energy received in the form of high frequency current is equal in amount to this, and then determine the amount of energy that will have to be put in at the sending end of the line, we obtain some very startling figures.

In obtaining these figures it is assumed that the high frequency receiving apparatus is equal in efficiency to the regular apparatus.

The commercial range for non-loaded No. 8 B. W. G. copper wires is about 1,000 miles and the corresponding lengths for No. 12 N. B. S. G. copper circuits and No. 13 B. & S. gauge cable circuits are respectively 450 and 61 miles. Using these lengths and making the comparison noted above we find that on the 1,000 mile No. 8 B. W. G. circuit it is necessary to put 4,000 times as much energy in at the sending end at 15,000 frequency as is required with 800 frequency, if the energy at the receiving end is to be equal in the two cases. At 50,000 frequency the ratio has risen to 300,000,000, while at 100,000 frequency the ratio of energy at this frequency to that at 800 frequency to obtain the same amount of energy at the receiving end is $7.(10)^{12}$.

On the 450 mile No. 12 N. B. S. circuit, the ratios for 15,000, 50,000 and 100,000 frequency are respectively 50, $3.(10)^4$ and $2.(10)^7$ while for the 61 mile circuit of No. 13 B. & S. cable the corresponding ratios are 500, $1.(10)^6$ and $3.(10)^9$.

Digitized by Google

These figures show I think that the problem of applying a high-frequency method of transmission to an existing wire plant would be an exceedingly difficult one, even if there were no other objection to the system and on the assumption that the required terminal apparatus could be readily obtained, due merely to the enormously greater amount of energy required at the sending end of the line. Furthermore, if the system were to be of any great value in a commercial plant, it could not be limited to a single frequency, but would require a large range of frequencies. The figures just given show that with such a range of frequencies the range of energy which must be supplied to lines of similar length will be very great if uniform transmission is to be given. While this might not be a serious objection in a plant comprising but few toll lines, it becomes one of very grave importance when a comprehensive net work has to be taken into account.

I have not as yet been able to see how this difficulty can be overcome in a way that will admit of applying this kind of a system to the complicated requirements of a commercial wire plant. Nor have I yet been able to find affirmative answers to certain other questions which must be satisfactorily disposed of before the device of high-frequency transmission can assume commercial value and proportions.

The more important of these questions are, first, the question of interference between high frequency circuits, 2nd, the question of signaling, and 3rd, the question of modifications required in the existing telephone plant to make possible the application of high-frequency transmission.

With regard to the question of interference, Major Squier points out very clearly that there is no interference between the ordinary talking currents and the high-frequency currents which may be superimposed on the same circuits. This point, can I believe, be granted without further consideration. There would be, however, in a commercial plant operated on the high-frequency system the question of interference between a circuit operated on one of these high frequencies and a neighboring circuit operated with another high frequency. To a certain extent this kind of interference could be avoided by a system of tuning for the terminal apparatus, as Major Squier points out, but we have only to glance again at the figures for the 1,000 mile circuit to see what difficulties there would be in the way of accomplishing commercial results in this manner. Let us consider for example the case of a toll line 1,000 miles long on which there are two pairs of No. 8 B. W. G. copper wires and assume that both circuits are being operated on a high-frequency method and are supplied with sufficient energy at the sending end to give commercial transmission at the distant end. If simultaneous sendings were always from the same end of the line there would probably be no great difficulty in eliminating interference even if there was considerable unbalance between the four wires making up the two circuits. In a commercial plant this simul-

Digitized by Google

taneous operation from the same end could not of course, be obtained, and we have to consider interference between sending on one circuit and receiving at the same end on the neighboring circuit. A consideration of the relatively large amount of energy at the sending end, to give commercial transmission at say 100,000 periods per sec. over a circuit 1,000 miles long shows that a degree of balance between the four wires of the system, which is commercially unattainable would be required to block out interference between the sending end of one circuit and the receiving end of the other circuit even where the two circuits are operated on two rather different frequencies.

Even if it were physically possible to obtain the degree of balance needed for the elimination of interference, that is to transpose the wires against each other at sufficiently frequent intervals, a scrutiny of the distance factors will show that with open wire lines constructed in the manner ordinarily employed for telephone plants, there are not a sufficient number of poles provided to make possible the necessary transpositions. On well transposed lines for ordinary talking circuits the transposition poles, that is the points at which the two wires of a circuit are turned over, occur on the average at between one-half and one mile apart, say from twenty to forty poles apart. When we come to consider high-frequency currents of from 15,000 to 100,000 alterations with their very much shorter wave length we find that in order to provide the same number of transpositions per wave length, we would not have a sufficient number of poles in the line as ordinarily constructed and would have to put in additional poles. From this standpoint also, therefore, it will be seen that there are very serious objections to any general application of the idea of using high-frequency current for the purpose of superimposing one talking circuit on another. The same objection arises in the case of cable circuits where current can pass from one circuit to another if there is any capacity unbalance between the pairs of wires which make up the adjacent circuits. Even in the present state of the art the degree of balance required to prevent excessive cross talk is very great and a high-frequency system would necessitate a degree of balance that appears to be commercially unattainable in the present state of cable manufacture.

In order to operate telephone circuits commercially it is necessary to provide means for signaling. The suggestion has been made that in a high frequency system this would not have to be done on the circuits themselves, but that all orders could be passed over special order wires. As noted previously, however, the full utilization of a wire plant in a system devoted to combined telephony and telegraphy practically requires the sending of both talking and signaling currents over the same wires. It would seem, therefore, that this point can not be dismissed so easily and that signaling apparatus must be provided on the talking circuits before a high-frequency system can be consid-

Digitized by Google

ered as having any great commercial applicability. Major Squier points out that in the particular circuit which he used, *i.e.*, a pair of wires in an underground cable, considerable reflection of the high frequency currents occurred at the protecting heat coils in the central offices. If this is so, it is evidence that even the simplest form of relay or retardation coil will act almost as a solid barrier against high-frequency currents unless it is bridged by a condenser.

Thus, even if we could get a sufficient amount of energy over the line it would be difficult to operate a high-frequency relay commercially and at the same time prevent its operation from extraneous disturbance. If, as in the case of the ordinary supervisory relay in a subscribers loop, the apparatus is in series in the line, it would seem to be almost impossible to insure proper signaling operation and at the same time to permit of efficient talking.

The necessity for bridging relays and impedance coils with condensers in order to permit the passage of high-frequency currents would be in itself a very serious bar to any general application of such a system, as it would not only greatly enhance the first cost of the equipment, but would also throw an unduly great burden on the maintenance force. Further, in the case of long distance telephone lines as they exist in this country today and as is pointed out in the paper by Mr. Gherardi on "Commercial Loading of Telephone Circuits," the tendency is to increase the efficiency of the talking circuits by means of inductance coils applied in accordance with Professor Pupin's invention. In this system inductance coils are placed in the circuit at definite intervals, the coils in some cases having an inductance as high as a quarter of a henry each. At the present time the entire toll plant in the long distance system of the American Telephone & Telegraph Co., is rapidly approaching the condition in which all of the circuits contain these inductance or loading coils. There are thousands of these loading coils distributed today along the open wire and cable circuits which form the telephone net work and the problem of applying and maintaining suitable condenser shunts of any form whatever around each individual loading coil would be well nigh insoluble. Also, the presence of these shunts would be seriously detrimental to the efficiency of the circuits for their ordinary use.

I have made one or two short computations to see what this shunting might mean, even assuming that we could maintain condensers around each loading coil, that is that we could build them to withstand commercially the effects of lighting low insulation, etc. For the purpose of comparison let us take the case of a No. 12 N. B. S. aerial copper line which is loaded with inductance coils of 0.25 henry each at eight mile intervals. Further, let us take a frequency of 50,000 periods per sec. which is about midway in the range suggested by Major Squier. In the computation I have assumed that we would

Digitized by Google

install at each loading coil a condenser of sufficient capacity so that the reduced attenuation of the line at 50,000 frequency would not be more than 2½ per cent higher than the attenuation at 50,000 frequency over the same line without any loading coils whatever. This would require a condenser of about 0.04 microfarads for each wire at each loading coil. While such condensers around the loading coils would keep the attenuation at 50,000 frequency down to about 2½ per cent higher than it would be if there were no loading coils on the wire, they would tend to destroy the effect of the loading coils for ordinary talking currents. If we take 1,500 frequency, which is above the mean telephonic frequency but is still within the range necessary for intelligible transmission, we find that the presence of these condensers around each loading coil increases the attenuation by about 7 or 8 per cent. It will thus be seen that for the sake of obtaining a reasonably good circuit for high frequency currents we would have to very seriously impair the talking frequency of our loaded lines when operated in the ordinary way.

In conclusion and as previously remarked I would say that I commenced my investigation of Major Squier's work with a great deal of interest, not only on account of the engineering features involved, but also because of the fundamental idea of the system appealed to me very greatly. In the course of this investigation I have had not only the pleasure of reading Major Squier's paper, but in addition the further pleasure of discussing his work with Major Squier personally and of examining his apparatus on the line in Washington and I can assure you that the experiments which he has performed over this line are indeed beautiful. There is absolutely no interference between the battery current and the high-frequency current and over the circuit which he was operating, *i.e.*, a relatively short cable circuit, it was easily possible to get a reasonably good volume of transmission with good articulation. As I have already said, however, I have not as yet been able to satisfy myself that there is any affirmative answer to the engineering questions which must be satisfactorily answered before there is any possibility of applying Major Squier's invention generally to a commercial plant used for universal service. I do not say, of course, that it may not be feasible to apply it commercially in certain localized cases where there are special reasons for desiring an additional circuit without the necessity for running additional wires. This could hardly be considered as a general commercial application, for the purpose of extending the range or efficiency of telephonic communication.

E. F. W. Alexanderson: I have prepared for this meeting a paper on "Magnetic Properties of Iron at Frequencies of 200,000 Cycles," but failed to get it ready in time for printing. I just mention this in connection with Major Squier's paper in order to show that a 100,000 cycle is not any longer the limit for mechanically generated frequency, but other-

Digitized by Google

wise it is quite clear, particularly in view of the figures shown by Mr. Jewett, that any frequency of 200,000 will be of no value at all for transmission over wires. I have had the same feeling in some experiments I made two years ago—that even 100,000 cycles is altogether too high to be used on a wire service. The experiments were made with the frequency of 10,000 cycles, and the same mechanical parts were used as the 100,000 cycle alternator. However, with a differently designed armature. The pulsating current of the microphone was used as the exciting current of the alternator, which was able to generate a high frequency current of much greater volume than the current used for excitation. The generated current was sent through a mercury rectifier and it was found that an image of the original telephone current could be produced. A special winding was used in order to increase the efficiency, so that the telephone current and the high frequency current flowed in the same conductors.

In connection with those experiments it was naturally thought that there is a possibility of transmitting a high frequency—in that case of 10,000 cycles, over a wire circuit, and in that way have the advantage of tuning the wire circuit to a definite frequency and avoid the distortion of wave shapes, which is bound to occur in ordinary long distance telephony due to the simultaneous transmission of different frequencies. It may be that even 10,000 cycles is too high, in view of the figures that we have had, and it might be out of the question to even use this system for transmission over wires. However, there may be hope for new developments that might solve the problem of long distance transmission. In fact, an alternator is just being constructed by which it is hoped that the frequency of 3,000 cycles can be used without interference with the voice, and in such a case it might seem reasonable that the telephone engineers would find a way of tuning their circuits to approximately 3,000 cycles, and in that way introduce some form of multiplex telephony by which messages may be transmitted long distances without distortion of wave shape or change in the quality of the speech.

John B. Taylor: There are a number of points of similarity between the electric telegraph systems and the electric telephone systems. Therefore, we can profitably look back over the attempts at multiplex telegraphy and see why some have worked out and some have failed.

Various means of separating one set of operators from another set using the same conductor, have been suggested or tried. Some of these means are: (*a*) difference in polarity; (*b*) difference in current strength; (*c*) successive assignment of the circuit to different operators, and (*d*) " resonance " methods. The paper under discussion is an example of the last method. These have all been suggested, and to some extent used on telegraph work. Some of them, I think, we can dismiss right away for the purpose of multiplex telephony.

Digitized by Google

Polarity seems to be pretty well out of the question, as telephone current is essentially an alternating current and it is hard to see how we can arrange to have one speaker use only currents of one polarity, while other speakers use currents of the opposite polarity.

A method depending on strength of the current seems to be quite out of the question, because the telephone current must go to zero and pass through various values.

The Gray harmonic telegraph system seemed to have great possibilities but as far as I know, it is nowhere in commercial use. In the paper under discussion we have offered a modification—harmonic telephony in which we are using frequencies so high that the currents do not interfere with standard telephone apparatus, and it is intimated that a number of frequencies may be used for independent telephonic conversations. The complications would seem to be much more in the case of the telephone than with the harmonic telegraph, and the latter has not yet proved successful.

The other possibility, the successive assignment of the line to one station and then to another, (in the "synchronous telegraph" use is made of a so-called "Sunflower" rotating distributor whereby the line is assigned for a short space of time, first to one operator and then to another) may be considered for telephony. It is surprising how much can be eliminated from the telephone current and still have recognizable speech. There are various ways of attacking the problem of multiplex telephony, and some have possibilities.

The system of multiplex telephony under discussion is a resonance method making use of intensity variations in the strength of an alternating current of frequency greater than that to which the standard telephone receiver and human ear are sensitive.

Major Squier refers to the possibility of solving the problem by the use of a similar method in which the transmitted alternating currents are of frequency below those to which the ear is sensitive, or in the neighborhood of 16 cycles per sec., but has apparently dismissed this from serious consideration on account of the difficulty of securing a pure sine wave. It may be well to point out here that entirely apart from any question of difficulty in securing a perfect sine wave of the frequency of 16 cycles or lower, that such a system is fundamentally wrong for purposes of speech transmission. That this is the case will be evident on slight consideration. Fairly rapid speech may have as many as ten distinct syllables in each second, so that one or more of these syllables occurring at or near the zero part of the 16 cycle wave, would be either entirely lost, or of such low intensity compared with those syllables occurring at or near the peaks of the 16 cycle wave, as to seriously change the quality of the speech. This is not equivalent to saying that speech over such a low frequency system could not be recognized, but that the distortions are so

Digitized by Google

great as to debar the matter from serious practical consideration. In some of my own tests, making use of alternating currents of relatively low frequency as a source of current supply in the transmitter circuit, instead of the usual cells of battery, and working with simple musical tones instead of the more complex speech, some very curious effects were noted, which can not be discussed at this t me beyond mentioning the fact that the simple musical tone of the source comes out of telephone receiver as a compound tone (generally a discord) apparently consisting of two tones, one of pitch corresponding to the sum and the other to the difference of the frequency of the muscial tone and the frequency of the alternating current source of energy.

Dr. Jewett has satisfactorily answered many of the questions that naturally come to mind on first acquaintance with the general scheme of Major Squier's system, and the figures Dr. Jewett has given showing the enormous sending current required for a moderate receiving current over a line of sufficient length to justify the employment of high frequency generators and other special apparatus, tell at least one of the difficulties in the way of putting such a system into commercial operation.

S. G. McMeen: Dr. Jewett's statement, as to the lack of the ability to signal over the strip of ether, impels me to remark that we have good, useful physical circuits today over which we can not signal in the ordinary sense. I refer to composited lines, from which the usual signaling ability is taken away by adding the telegraph. But we do use such circuits to great advantage, and without trying to signal over them.

Dr. Jewett comments on the hurtfulness of series windings, such as relays, in these high-frequency circuits. Series windings, other than loading coils, have steadily become less common in all telephone circuits during the last 20 years. All reactances required in Major Squier's methods, whether of capacity or inductance, are of small dimensions because of the high frequencies. It easily may come about that the capacities may be sufficient when formed of a few turns of wire laid side by side.

Mr. Alexanderson says there is hope for further development. It is that outlook which makes this work notable. Since 1900, there has been no announcement of large addition to our fundamentals in telephony. We may well consider this work another such addition.

Mr. Taylor says the harmonic telegraph did not make good. It *did* give us one great result: Observation of a single phenomenon in harmonic telegraph experimentation diverted Professor Bell directly to the invention of the telephone.

Dr. Jewett further says that Major Squier's invention is "a beautiful laboratory apparatus." I beg to remind him that the telephone itself was that, *and that only*, when Professor Bell finished it.

Frank F. Fowle: Major Squier's achievement in duplexing a telephone circuit by superimposing waves of a frequency be-

Digitized by Google

yond the range of audibility will rank high among scientific accomplishments. It marks a new and extremely interesting development in the art of telephony.

Telephone engineers will analyze it in the light of their experiences with voice transmission, at relatively low frequencies, ranging from 100 to 2,000 cycles per second. As others will doubtless point out, it appears to have serious defects and a very limited commercial value from such a standpoint. There are two fundamental reasons for this. In the first place, the rate of attenuation at such high frequencies will be relatively enormous in comparison with the values of attenuation now obtained with voice frequencies. Consequently the maximum attainable distances will fall far short of present accomplishments, even at comparatively high impressed voltages. Secondly, and perhaps of most import, the difficulties of preventing cross-talk between two or more high-frequency circuits in the same cable or on the same pole line appear to constitute an almost insurmountable problem.

For these reasons Major Squier's invention seems to have a very limited commercial value at present, at least in relation to its use on existing wire plants. As to its ultimate value it is unsafe to predict, because it opens the door of a new development whose possibilities are yet unexplored.

The two large problems needing immediate attention are those of minimizing the attenuation and controlling the cross-talk. It seems fairly apparent that the lowest safe frequency from the standpoint of interference will be the best one, because thus the attenuation is made a minimum. The control of cross-talk is perhaps the most difficult problem. In this connection it may well be pointed out that for high-frequency transmission the present situation is parallel to the one which existed 30 years ago in the development of long distance transmission at synchronous frequencies. The grounded line of those days gave serious trouble from cross-talk as soon as appreciable parallel lengths were exposed to each other. The metallic return diminished the difficulties but was not a satisfactory remedy. It was not until the transposed metallic circuit was developed, through the work of Carty and Barrett, that long-distance service became commercially feasible in 1885.

Apparently the wire plant of today will need radical alterations to permit secret transmission over high-frequency circuits lying side by side for many miles. If this can be accomplished without sacrificing present efficiency in relation to the use of the composite and the phantom, it will bring Major Squier's achievement to a state of great social and industrial value.

In connection with the paper I note that the measured constants of the cable circuit employed are very unusual. The measured loop resistance averages 110 ohms per mile, which is normal with the gauges used. But the capacity of 0.69 microfarad, if it represents the whole seven miles, is much too low;

Digitized by Google

it might be very nearly right if it represented the mutual capacity per mile. The insulation resistance is exceedingly low and indicates very poor conditions somewhere in the circuit.

Béla Gáti: I have made a number of experiments from which I conclude that Major Squier's explanations are not always right.

It seems Major Squier has not enough measuring instruments for alternating (high frequency) currents. Major Squier measures the capacity (one minute electrification) and the insulation resistance with direct currents. He does not say so but the "one minute electrification" verifies my opinion. I have written a number of articles discouraging the use of direct-current measurements for high-frequency circuits. There is no connection between direct-current isolation and high-frequency dielectric resistance. I found the latter one is 1,000 to 10,000 times smaller than the direct-current value. I believe the isolation (dielectric resistance) of the said telephone cable can be only some hundred ohms. I should like to have data obtained by measurement with 20,000 to 100,000 cycles.

Major Squier states that: "The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles . . . ." This opinion is the most dangerous one imaginable, for the future. We know that in wireless telegraphy the damping factor depends, in the first place, on the energy consuming resistances. How Major Squier's opinion was formed, can only be explained as follows (*a*) by the phenomena on that when the current is over a certain value, (5 milliamperes on the Hungarian receivers) the telephone receiver does not give a stronger sound. I showed these curves relating to this phenomenon at the second conference of the Telephone Techniciens in Paris. If we have 4, 8 or 12 milliamperes received currents in the receiver, the sounds remain about of the same strength and so we cannot judge, by hearing, the strength of the incoming currents, nor the total resistance of the line.

(*b*) As I have already stated the insulation for high frequency current must be very small, the capacity between the wires is large enough, the cross-talk for these cycles exists and so we cannot speak about the ohmic resistance of one wire, but only of the whole cable bunch. Major Squier found the transmitting impedance under 100 ohms (87) for high-frequency-currents, and one metallic circuit had 776 ohms resistance.

(*c*) I experimented with telephoning on single aerial wires. I had the same effect at the receiving station (2,500 km. 4 mm. diameter bronze wires), whether the two wires were connected in parallel or not. Then I changed the line, using a three-mm. wire, and have spoken over only 1,000 km. instead of 2,500 km. In this case the whole line, if the cross-talk is not avoided, forms only one wire.

I hope that Major Squier will make other experiments and verify my explanation. Assume for example, that The Com-

Digitized by Google

mercial Cable Co. should have a new cable laid between New York and England with a self inductivity 10^{-2} henry per kilometer, but 10 ohm resistance instead of 0.9 ohm, provided Major Squier's opinion about the ohmic resistance is a correct one. This new cable with 10 ohms per kilometer would be a complete failure, but with 0.9-1 ohm resistance and with the same 10^{-2} henry inductivity this could alone make up for all the other Atlantic cables and make the cable rates 10 times cheaper.

The present type of microphones are not fit for high-frequency currents. The microphone effect is caused by the imperfect contacts; for high-frequency currents there are no imperfect contacts; they make conductive the worst contacts of the crystal detectors, therefore the need is felt for another type of

TABLE I
THE SPEED OF ELECTRICITY ON BRONZE WIRE TELEPHONE CIRCUITS

$\omega = 2\pi n$ =	v =
9000	240,000 km.
8000	239,500
7000	239,000
6000	238,000
5000	237,500
4000	235,500
3000	231,500
2000	222,000
1000	196,000
628	173,000
263	133,500
131	112,500
62	101,000
31	97,000
18	95,500

microphone. I made experiments with 4,000 cycles, and was able to throw out the disturbing effect of the ground-current. Today, I believe the frequency of about 10,000 cycles is the best. The telephone receiver does not respond to disturbances when the cycles are over 7,000.

Telegraphy with high frequency currents is an old thing, I experimented with it many years ago and worked it out especially for cable telegraphy. I am glad that Major Squier's experiments confirmed the unlimited possibilities of this kind of telegraphy; perhaps existing cable-companies will now pay more attention to it.

Major Squier uses the $\lambda = 2\pi V\sqrt{L C}$ expression and supposes that $V = 300{,}000$ km. per second. According to my experiments on aerial lines Table I it can be said that the speed is

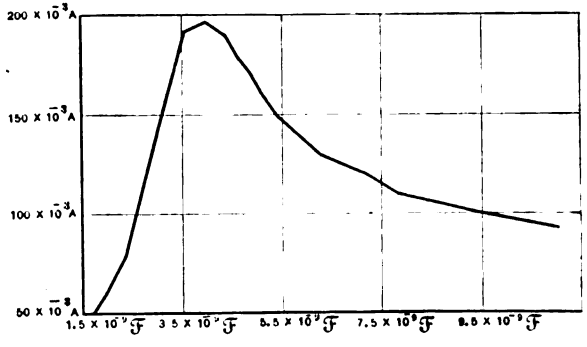
Digitized by Google

never 300,000 km. I made various experiments and have never found this value. I do not believe that this 300,000 km. is a definite value. According to Kennelly's formula $V=\frac{w}{\beta_2}$ where

$$\beta_1+j\,\beta_2=\sqrt{(r+j\,\omega\,l)\,(g+j\,w\,c)}$$

I will not say that in the case of the cable line $V=500{,}000$ km., as the preliminary computation shows this, but I am of the opinion that V differs from the value of 300,000 and so the resonance curves and other computations of Major Squier are incorrect.

The same is applicable to the L^1 0.260 millihenry value. The cable line has a comparatively large capacity joined in series with the tuning capacity; this also somewhat modifies the result.



Resonance curve

I believe for effective voltage measurements the string electrometers, for instance Woulff's electrometer with short platine string, are sensitive enough even for small values. The impressed voltage is surely larger than one volt, and thus measurable.

In my experiments the resonance curves were also unsymmetrical. I constructed curves at one single frequency; the ordinates were the currents in milliamperes, the abscissas were the capacity values in microfarads. I found the cause of the unsymmetrical position in the dielectric resistance of the condensator. According to my experiments 0.001 microfarad has at $w=2\,\pi\,n=10{,}000$ a dielectric resistance, (isolation) about 1 megohm, but 1 microfarad capacity has about 1,000 times less, that is only 1,000 ohms. This dielectric resistance is not constant, it is for higher frequencies less so; I believe this diminution of the isolation (dielectric resistance) for higher frequencies causes the unsymmetrical state. I obtained the values of

Digitized by Google

the resonance curve, ($n = 95{,}200$) according to my process, the ordinates were the milliamperes, the abscissas, the capacities. This curve was very unsymmetrical.

I constructed the curves, not only for the outgoing but also for the incoming currents. In wireless telegraphy from these resonance curves the attenuation is computable. Of course, the hypothesis is that the curve of the resonance is symmetrical; perhaps some one could find the mathematical expression of the attenuation from these unsymmetrical curves. It would be very useful for long distance telegraphy to have them. The measuring of the ratio of the outgoing and incoming current is only over some thousand kilometers distance appliable; at this distance, the disturbing (vagabond) currents are always larger than the talking currents, and so the measurement is very difficult.

The selectivity curve is in reality the same as the resonance curve; hence the unsymmetrical position.

Of course, it would be more interesting to know the selectivity curves of the received (incoming) currents. My barretter set measures without shunt to one milliampere, with shunted galvanometer, to 5-10 milliamperes maximum values (pointer-galvanometer) beginning the measurement with 0.5-0.1 milliampere, which is the value of the commercial talking (received) telephone-current. If Major Squier wants to make experiments over some 100 or 1,000 kilometers, he will need this instrument, therefore I call his attention to it.

The manufacture of large condensers with large dielectric resistance is the most difficult problem in high frequency telegraphy. Perhaps it would be of interest to know that I use the condensers of Mr. Szvetics, (the director of the Telephone News, in Budapest) which I have found the best and the most practical for this purpose.

On cables, the voltage has no intention to rise after having thrown in resonance, but on aërial lines I experienced the increase of the received currents. At open ends there is always increase in voltage. Probably Major Squier will make further experiments with 100,000 cycles, I should like to know the results.

The small dielectric resistance (isolation) of the cable causes the phenomena, that the resonance curve is the same when the distant end is open or short circuited. I experienced on aerial-lines that the outgoing current was always larger when the distant end was *opened*. At the short circuited distant end the outgoing current is only a small value of the former. This seems at the first moment very strange, Kennelly's formulas (hyperbolical treatment of telephone-currents), however, explains it quite correctly.

When the impedance of the whole line is 87 ohms, it is not permissible to measure with a galvanometer which has 171 ohms. The so called attenuation curve in Fig. 22 Major Squire's paper

Digitized by Google

is the attenuation curve of this galvanometer (at least 60 per cent) and not of the line. When the outgoing current decreases from 240 milliamperes to 5-1 milliamperes at 11.26 kilometer distance, it proves the system to be a disadvantageous one. With barretter-set (1-10 ohm resistance) Major Squier could obtain more current at the receiving end. We see here, that the effective ohmic resistance is a very important one for these high-frequency currents. Of course the outgoing current must be in resonance.

I have the same opinion regarding the submarine cables, as Major Squier. A cable with 10^{-2} self inductivity per kilometer and working with high-frequency current would be able to settle the whole business of the existing Atlantic cables. The rates could be decreased to two cents per word. This time is not so far off; however, at the present time, the cable companies are too conservative. On account of this, I emphasize again, that the ohmic resistance of the wire is a very important one, and one unsuccessful experiment could cost millions of dollars and prevent the application of the high-frequency currents for some decades.

Finally, allow me to congratulate Major Squier. My above remarks are not intended as a criticism. I had no intentions of that kind. I simply wanted to communicate the results of my experiments, made during the past eight years and thereby hasten the development of high frequency telegraphy and telephony. I will further remark that with high-frequency currents, the speed is unlimited. I succeeded in sending 20, to 60 letters per second. The signals are not intermixed, the incoming signal is not expanded as in direct-current telegraphy. The German Telephone Experiment Station in Berlin (Mr. K. W. Wagner) claims and also deducts mathematically that the signals are expanded at high-frequency currents. But this statement is quite incorrect. I have made experiments over a 4000-km. line; the direct-current signals were expanded, perhaps 300 per cent, the alternating current signals, not at all.

Telephoning with high-frequency currents has also been attacked, but I proved mathematically (Electrotechnische Zeitschrift, 1909, copy 39) the possibility of talking between London and Kurachi (India) a distance of 8000 km.

This statement as well as a lot of statements like the expansion are ones which we are obliged to disprove with experiments. I should be very glad if Major Squier as well as others would continue experiments along these lines so as to help us in this matter.

Digitized by Google

A paper presented at the Pittsburg Section Meeting of the American Institute of Electrical Engineers Pittsburg, Pa., May 9, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

THE COST OF ARC LIGHTING AND GENERAL SERVICE FROM MEDIUM AND SMALL SIZE MUNICIPAL OR PRIVATE PLANTS

BY W. EDGAR REED

Much attention has been given to the large power plant in technical publications. This paper, on the other hand, will consider the costs of lighting and general service from the numerous small plants where the cost of service is so frequently and persistently referred to, not only before the plants are constructed but periodically during the operating life and also every time a lighting or power contract is let, a new unit is added or other extensions are proposed. As an example of this, at every renewal of arc lighting contracts with private plants there is generally severe competition and rates must be right to retain this business. Franchises for lighting and power generally go with the arc lighting contract, and if the latter business is lost, competition in all other branches is immediately introduced. This means furnishing arc lighting at little or no profit in many cases in order to retain the incandescent and power business which should in this case make a profit for the entire plant.

Since the active uniting of small plants was started, this question of costs has been presented more frequently than formerly and is of interest to both the large and the small plant.

The difference between the lower switchboard costs of the combined plant and the replaced ones must pay for the transmission to the main distribution centers, the investment in the unused part of the small plant and installation, less salvage, and for the investment in and operation of any additional substation or distribution apparatus required.

The question many municipalities, manufacturers and other

Digitized by Google

consumers face is, whether they shall build their own electric plant or purchase arc lighting and current for general service. This matter should be decided upon the cost and service basis, but these matters are perhaps more frequently determined by guessing than by engineering and business methods. Many municipalities decide to purchase or build without knowing which is advisable and will spend thousands of dollars building or lose hundreds of dollars in operation rather than pay a small engineering fee to find out what should be done. There are cases where water, light, ice and cold storage, garbage incinerators, sewage disposal and other municipal departments have separate plants operating at a loss while the plants if combined or properly designed would earn a respectable profit. There are also cases where current can be purchased for less than it is actually costing to generate it and where extremely poor municipal service exists years after the same private service would not be tolerated. Let us consider the principal factors in the above paragraph.

Service. Few small municipalities consider service or make lighting contracts properly covering this subject. For arc lighting the nominal candle power is generally stated, the kind of current given and sometimes the watts consumed at lamps are stated but seldom, if ever, checked. The illumination is in perhaps 90 per cent of the contracts not even mentioned. All kinds of lamps and illuminations are frequently considered equal in cost comparisons. An ample reduction for outs is generally included when lighting is purchased, but seldom considered in figuring comparative costs from plants. In street lighting practically continuous illumination of proper intensity is the important item in comparisons or contracts. An ideal illumination would give uniform intensity at all places. It is necessary, however, in practice to have distributed lighting units which do not meet ideal conditions although attempting to come as close as possible to them. This involves the mean lower hemispherical candle-power and its distribution, in determining illumination at all points between consecutive lamps. Generally the illumination near the lamps is many times that half way between lamps, and lamps which have practically the same mean lower hemispherical candle-power do not give the same street illumination.

For lighting and power the limits of voltage variation, continuity of service and systems best suited to the requirements should be selected.

Digitized by Google

Cost. The question of cost is always considered and generally in dollars per arc lamp per year and cents per kw-hr. for other purposes. The question of costs seems at first view an easy matter which many municipalities and private concerns undertake to determine without engineering assistance. The usual proceeding is to inquire at surrounding plants the costs of plant and current. Sometimes costs from plants operating under similar conditions are considered and sometimes not, but in many cases any neighboring plant is too frequently taken as furnishing sufficiently accurate data for starting projects involving the expense of considerable sums and chances for loss in each year's operations. At this time the general opinions of many people are sought including the sales agents who volunteer favorable data. This method cannot possibly be advised by any one who is familiar with this question, and the experienced business man will say the risk is great enough even with the best engineering experience and study of conditions. Central station facts and factors may be of general assistance provided all the conditions are similar. To illustrate this we may first mention briefly some of the principal items of and conditions which affect the cost of power and then consider how much dependence can be placed on cost information generally furnished by any one in a power plant. This will show that a complete engineering investigation only will show what may reasonably be expected from plants and that this investigation should be made before considering either building a plant or purchasing power.

To show the impossibility of determining costs from incomplete data on other plants I give a list of prices paid in various cities for lighting.

Place	Number of lamps	Contract life years	Watts per lamp	Cost per lamp
Toledo, O.	2000	10	320	$45.00
Buffalo, N. Y.	700	5	320	52.00
Bridgeport, Ct.	645	1	320	73.00
Washington, D. C.	——	3	320	85.00
Rockland, Me.	118	7½	320	85.00
Wooster, Mass.	873	1	320	91.25
Syracuse, N. Y.	1500	5	320	68.00
Poughkeepsie, N. Y.	373	3	320	80.00
Chillicothe, O.	200	10	320	70.00
Newport, R. I.	165	7	320	104.25
Fall River, Mass.	862	5	320	91.25
Lancaster, Pa.	445	5	320	80.00
Harrisburg, Pa.	584	3	320	68.00
Reading, Pa.	700	5	320	67.50
Washington, Pa.	40	5	320	70.00
Philadelphia, Pa.	13258	——	——	94.63
Boston, Mass.	——	5	500	103.54

Digitized by Google

ITEMS AND CONDITIONS AFFECTING COST

Installation Cost. Fixed charges on investment, interest, depreciation, taxes, insurance.

Operation Cost. Operating plant and distribution, labor and material, fuel, oil, supplies, maintenance, miscellaneous.

General Expenses. Legal, office, management, collections, bad accounts, accidents, extraordinary.

Source of Power. Steam, water, gas, etc., or a combination of these.

Individual Light Plant or Combined with Water Works and other Departments.

Line and Distribution Losses.

The System, Uses and Size of Plant.

Minute variations in *local conditions* effect cost of erection and operation of engineering works and these costs fluctuate from year to year with business and other conditions. Erection and reproduction costs vary, unit costs of similar work done at the same or different times may be different. There is enormous difference in the *operating costs* of different plants and especially in small private and municipal plants.

Dependance Upon Data. No data can be of value without a thorough investigation of all the factors and accounting methods used in arriving at the figures. Complete and standard methods of accounting are used by few municipal and small private lighting concerns. For street railways the Interstate Commerce Commission has formulated some good systems, but the application of similar ones are needed to lighting concerns. It is remarkable how little is known about the real cost of lighting and power from small stations and results are frequently stated that are impossible. In the past, depreciation has been neglected perhaps more often than any other item, although interest on the investment is not considered on some municipal plants also and maintenances is in some cases greatly neglected.

After proper and uniform accounting is secured all the items given above under general conditions affecting costs and other factors, should be considered in making comparisons. The difference between operating and *total costs* should be properly understood. I have known cases where plant operation was taken as the total power costs when the remaining items would almost double the figure.

Digitized by Google

In comparing arc light costs the following items should receive attention:

Outs. Few lamps burn the full scheduled yearly hours. The fewer hours lamps are out the better the service. The reduction of outs to a low figure means additional expense for inspection, repairing, cleaning and spare machinery and supplies, etc. In large cities there is generally a deduction for outs from the price paid private plants for lights. In small towns generally there is a small or no deduction. In municipal lighting plants there is generally no deduction. Where there is a difference in outs there is then a difference in service which should be properly considered in comparative costs, for the better service costs more to furnish. Numerous methods of figuring deductions have been used, but no one can yet be considered a standard. Generally, however, the deduction is based upon price paid per lamp hour and total deduction found by multiplying this by the outs in lamp hours. In cases no deduction is made unless the lamp has been out more than one hour. In other cases the outs before midnight are charged at double the price paid per lamp hour. And when individual lamps are out three hours they are considered as out the entire night. There are also additional penalties when a whole circuit is out.

Reduced Illumination. Lamps operated at less than normal current or watts will give considerably less illumination with a reduction in cost due principally to saving in energy and carbons consumed and trimming. In some few places there is a reduction in price to cover this. One installation provides as follows: $\frac{1}{4}$ cent per hour reduction for each 5 per cent reduction from normal amperes or watts. When the reduction is greater than 15 per cent the lamp is considered out.

Recording instruments will show current and watts during each night's operation.

Tax on Poles. There are few places where there is not a pole tax on private installations. This varies in different cities up to $1.00 per pole and guy stub. Municipal plants do not, however, charge themselves, although the same installation by private concerns would mean an income to the city. This tax should properly be considered in private and municipal cost comparisons as it depends entirely upon local conditions.

Insurance. Fire, accident and liability, boiler and other insurance varies for different installations and therefore affects costs. The amount and kinds of insurance should be consid-

Digitized by Google

ered in comparisons as they require proper construction, suitable safety devices, and protect against poor and dangerous maintenance.

Borough and County Taxes. There is a wide variation in taxes which fluctuate from year to year and should be determined for the specific case in question.

Insurance and taxes are frequently figured at 2 per cent on investment which may be quite inaccurate. In this district taxes run from 6 to 26 mills and insurance from nothing to perhaps the highest rates in the world. Some municipal plants pay no taxes while private plants would bring this income to the borough.

Federal Tax. Large private or combined plants pay a federal tax on earnings over $5,000. Combined or larger plants must bear this increased burden over small ones.

Use of Poles. Municipal distribution systems frequently have the right to use part of other private company's distribution systems free of charge. As this is considered as part payment for right of way private plants doing municipal lighting should also have this right, reducing cost and number of pole lines.

Free Lighting. Private plants frequently furnish free lighting to city buildings and in these cases the cost of this item must be considered as increasing the cost of lighting.

In considering competition between private, combined and municipal plants there are also other costs which will be different.

Telephone Service. Municipal plants generally have reduced or free rates which private plants do not obtain. We believe this should also be treated in the same way as free poles or part of poles.

Franchises and Rights. Cost of franchises is quite different in different places and is more for private than for municipal rights. Time and money spent in this way increases the investment upon which a reasonable profit must be made. The greater the duration of franchises the less this yearly cost will be.

Bonds. Municipal bonds generally sell at a better price and have a lower interest rate than private bonds. Which means promotion, financing and operation may be less than in private plants.

Operation and Labor. It is not infrequent that the class of operatives in municipal plants are less efficient than in private plants which means higher labor costs.

Digitized by Google

Management. In some states municipal plants are managed by Boards of Public Service or paid councilmen and mayor and a part of this expense is properly chargeable to the light plant. In other states the unpaid city councils perform this duty free of charge.

Extraordinary. After all current expenses, fixed charges and depreciation are determined there are extraordinary and unforeseen expenses for every plant due to accidents, lightning, cyclones or heavy storms, explosions, great conflagrations, acts of strikers, etc., the cost of which is impossible to predetermine, but which exist, however, and reserve funds are frequently provided in private plants for such emergencies. Municipalities, however, do not provide for such circumstances, but appropriate funds to take care of trouble when it occurs. But these items certainly increase the cost of manufacture and should be allowed for.

Profits. Investors in private plants are entitled to a reasonable profit over and above the usual interest rates depending upon the risk incurred. The shorter the contract the greater is the risk. Municipal plants frequently claim small profits or eliminate them entirely trusting that exceptional expenses will not be incurred and knowing that the city can easily provide them when necessary.

Depreciation has been overlooked at times because its effects are only apparent after intervals of several years while profit and loss are determined yearly. If earnings were determined daily expenses that are paid say monthly might similarly be neglected for a time. This would mean large daily earnings for sometime and then a large daily loss until the debt was removed. Again if profit and loss were determined every 50 years depreciation and extraordinary expenses would undoubtedly not be forgotten and fat and lean years would be averaged so as to give a more uniform rate of profit. There would then be no distinction between maintenance and depreciation. In declaring yearly profit and loss it is necessary to consider these and provide for expenses that must be met at more than yearly periods by putting aside for the future needs part of each year's earnings.

Maintenance. This is the current repairs and detail replacements of parts that deteriorate rapidly and must be taken care of frequently in order to keep the plant in operation. This is an operating expense included in the yearly expenditures. There is good and poor maintenance depending upon whether the plant

Digitized by Google

is kept in the best operating condition or otherwise. But after a number of years generally it is advisable, or necessary, to replace a complete machine or the entire installation and repairs or detail replacements will not suffice to render the further operation economical or even possible. This condition is due to depreciation, and as it may not be encountered for a number of years after operation has begun, it is, therefore, not included in yearly expenditures.

Depreciation is a diminution of value due to wear and tear, time, decrepitude, obsolescence, inadequacy, etc. Decrepitude is a gradual wearing out from age and use and ending of the useful operative life. This occurs when operation, maintenance and fixed charges on new unit is less than operation and maintenance of the old unit. It can not be overcome by current maintenance of the parts. Obsolescence is a reduction of the economical life due to advances in the art which limit the useful life before decrepitude, or when saving in the operation of new unit pays more than the fixed charges. Inadequacy, which may be considered as obsolescence, is the discarding of serviceable parts or complete installations on account of growth of business, combining plants, new laws or ordinances causing changes for esthetic or other reasons, old units not of right kind or size, and substituting underground for overhead construction. Short life contracts and franchise may require depreciation based upon their life.

Depreciation is generally a large item in costs of electric plants and it is taken care of by depreciation or amortization funds. The yearly depreciation is not uniform but varies at different periods during life. This is a broad question of itself and can not be covered by this paper, but the figures given are for a uniform percentage depreciation for each year. It is figured on the straight line basis as follows:

$$\text{Annual depreciation} = \frac{\text{wearing value}}{\text{years life}} = \frac{\text{first cost—salvage}}{\text{years life}}$$

Salvage equals junk or other value less cost of removal and sale or disposal and may have a negative value.

The useful life can only be determined by those thoroughly experienced with the apparatus used and conditions of service and the rapidity of advancement in the art, design and con-

Digitized by Google

struction of machinery for the purpose. The higher the first cost the less the maintenance and the longer the useful life should be. The maintenance may have considerable effect on the decrepitude life.

Tables are compiled of the life of various parts of installations, but these must be used with caution as various conditions may change them considerably. Boiler installations may be used to illustrate this. Data from different tables published give an average life of 14 years, a minimum of 6 and a maximum of 25 years. The correct life depends upon the quality, kind, make, service and conditions. The water for example may change the life depending upon its deteriorating effects. The impurities, therefore, enter. A purifying filtering or heater system will change results. The thickness and quality of plates, type, load, kind of maintenance, hours of operation, whether feed water heater and regulator are used, etc., will also change these figures.

More accurate results will be had by considering all the factors mentioned above instead of taking the average life from tables, which generally cover only decrepitude.

It is advantageous in auditing and accounting to have the total or average percentage depreciation on the entire or important divisions of the installation. Parts of installations have quite different lives and it is necessary in arriving at a reliable figure to consider the life of component parts and their total cost installed. The following shows probable decrepitude life of parts of a definite distribution system.

	Years
Poles—Cedar 35 ft., 6 in., tops in earth untreated	12
Cross arms, yellow pine, 6-pin, untreated	7
Pins, locust untreated	6
Insulators, porcelain	12–15
Hardware, galvanized	8–15
Cut outs, porcelain	12
Lightning arresters	6–8
Copper wire (weatherproof 10, sulphur atmosphere 5)	20
Guy wire	8
Mast arms, heavy	14
Arc lamps	8
Arc cut outs	8
Miscellaneous	

The items in this table vary with conditions. If poles are treated or set in concrete their life and cost is increased. If set in stone, concrete sidewalks, etc., first cost is greater. The life of some other kinds of arms and treated arms is also longer.

Digitized by Google

The life of some parts may influence the life of others. If a pole for example must be removed when the cross arms are in rather poor condition, although serviceable, it is probable that new ones would be put up. It is, therefore, necessary to consider the life of units and also the various parts composing this unit. Separate units and the complete installation should then be considered in finding the percentage for whole installation.

The data can be conveniently tabulated using the following items. Parts having same life may be grouped together.

Items	Installed date	Useful life, years	New cost $	Salvage $	Wearing value $	Yearly depreciation $	Yearly depreciation per cent
Totals.....							

$$\text{Average percentage depreciation} = \frac{\text{yearly depreciation (total)}}{\text{new cost (total)}}$$

I believe I have mentioned all the factors that generally enter in the above situation and have shown that conditions affect costs to such an extent that no two plants are actually operated under the same conditions. Each case must be considered and some special factors not generally found may then be developed.

Purchasers of light and power should realize that any special requirements such as pole tax, rigid deductions for outs or reduced illumination, severe service and regulation limits, free lighting or franchise taxes and rights-of-way charges mean an increase in cost of producing and therefore that the minimum rate charges must be raised to include these items.

Plant Data

Below are given some data on a combined municipal water and light plant which has given excellent results with the systems employed. The employees are few in number and efficient. The engineer and superintendent, to whom we wish to give credit for furnishing data and assistance, is capable and energetic and it is largely to his efforts that the plant makes such a creditable showing.

Digitized by Google

The data are for a steam-driven plant which is located on the Allegheny River Bank, and which serves a population of 8150 people. There are 1400 water consumers and water is pumped from ten 12-in. wells into city mains at 85 lb. pressure. The daily consumption is about $1\frac{3}{4}$ million gallons per day and the very approximate cost is $3\frac{3}{4}$ cents per 1000 gallons. The pumps now in operation were installed in 1886 so that they have had 25 years' service.

The electric plant furnishes arc lighting and 24-hour constant potential service to 350 paying consumers. No income is received from public buildings. The constant potential system is alternating current 1100 to 110 volts service; maximum plant capacity, 310 kw.

INVESTMENT

Real estate, building	$ 23.00	per kw.
Machinery and boilers, etc	61.00	"
Distribution system	58.00	"
Total	$142.00	"

Operation and general including everything except distribution	1.53 cents per kw-hr.	— 66 per cent	
Depreciation 5½ per cent	0.46 " " "	— 20 "	
Interest 6 per cent	0.31 " " "	— 14 "	
Total	2.30 " " "	—100 "	

This does not include profit, exceptional expense and distribution costs, and shows depreciation amounts to 20 per cent of total cost even with very conservative figures.

Arc Lighting. The direct-current series system is installed and operates 100, 6.6-ampere enclosed arc lamps. The plant installation consists of one steam engine belted to two arc generators of 50 lamps capacity each, switchboard and appurtenances.

The investment is as follows:

Land, building	$ 36.00	per lamp
Machinery and boilers, etc	75.00	" "
Distribution system	64.00	" "
Total	$175.00	" "

A convenient method of showing the items and depreciation in this case is given below. Here the cost of current supplied to the arc circuit from the switchboard is determined first and the cost includes no profit and exceptional expenses. These

Digitized by Google

figures are based upon 4000 hours service, 495 watts per lamp and 10 per cent line loss.

	Total cost	Without depr.	Without interest and depr.
Current at 2.3 cents kw-hr	$50.14	$40.11	$33.43
Trimming	2.10	2.10	2.10
Carbons	1.00	1.00	1.00
Globes	0.75	0.75	0.75
Lamp repairs	0.60	0.60	0.60
Inspection and maintenance, tree trimming	0.15	0.15	0.15
Pole tax, and right of way, 50 cents each	0.68	0.68	0.68
Taxes, 6 mills on $42.00	0.26	0.26	0.26
Interest 6 per cent on $64.00	3.84	3.84	——
Depreciation 8½ per cent on $64.00	5.44	——	——
Outs reduction of candle power	——	——	——
Profit	——	——	——
	$64.96	$49.49	$38.97

Depreciation	$15.47	per lamp per year.
Interest	10.52	" " " "
Depreciation and interest	25.99	" " " "
Power plant labor	8.85	" " " "
" " fuel	16.64	" " " "
" " supplies	5.20	" " " "

The total appropriation is less than $40 per lamp per year.
No funds are provided for interest, depreciation or profit.

These figures do not include a deduction for outs and low candle-power as these are not enforced on the plant. Nor do they include profit or reserve fund to meet exceptional expenses. The taxes are rather low at 6 mills on two-thirds valuation. The poles tax is at 50 cents per pole the price charged other companies. The inspection, maintenance and tree trimming are very low as part of this real cost is included under trimming lamps and can not be separated. The total insurance runs about $110 per year on the combined water and light plant. The telephone service is obtained at a very low figure. The bonds pay 4 per cent. The labor is very economical, two men per shift operate the combined power plant on 12 hour shifts. The superintendent and engineer divides his time between water, incandescent and arc lighting systems. The depreciation is conservative.

Approximate Value of Special Items

It is interesting to know how much the items not entering in above detail figure amount to in other cases where they apply.

Digitized by Google

A conservative estimate of cost of *outs* when there is such a deduction in contracts may be figured for small plants on the basis of one day out in every two months operation or at about $1\frac{2}{3}$ per cent. At the rate paid per lamp per hour this would be approximately $1.00 per lamp per year.

The *profit* should be for a long term franchise and contract at least 6 per cent in order to attract investors to such undertakings.

The *reserve* fund should probably be at least $\frac{1}{2}$ per cent on the investment.

Free lighting will average for small plants, 50 16-candle power lamps for which the yearly cost will be at 4 cents per kw-hr. and 1000 hours burning about $1.10 per lamp per year.

Emergency connections vary in cost so much that it is difficult to give a figure.

Normal telephone rates would be approximately $.50 per lamp per year higher than actually paid at this plant.

Digitized by Google

Digitized by Google

A provisional report from the American Committee, subject to, and until such time as the official report of the Commission shall appear

Copyright 1911. By A. I. E. E.

TURIN MEETING OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION SEPTEMBER 7–13, 1911*

Historical Outline

It was voted by the Chamber of Government Delegates at the International Electrical Congress of St. Louis in 1904, that an international electrotechnical commission should be established to carry on the work commenced at that Congress. The commission came into official existence in 1906, owing, in large measure, to the work of Colonel R. E. Crompton, C.B., who has served as its honorary secretary from its inception. The initiation of the organization was thus a sequel to the work of the St. Louis Congress. The first meeting of the commission, for organization, took place at London in 1906, and was attended on behalf of the American Institute of Electrical Engineers by Messrs. F. B. Crocker, C. O. Mailloux, and C. H. Sharp. Lord Kelvin was elected the first President of the Commission, an organization was formed, and statutes adopted. M. C. leMaistre was appointed General Secretary with an office in London, at 28 Victoria St.

A council meeting of the Commission was held in London in 1908, and was attended by Mr. C. O. Mailloux on the part of the United States Committee, appointed by the American Institute of Electrical Engineers. Professor Elihu Thomson was elected President on the demise of M. Mascart. Work was commenced at this meeting. Inasmuch as a principal difficulty in the deliberations of any internationally selected body lies in

*A provisional report from the U. S. National Committee to the Board of Directors of the A. I. E. E., and subject to such official reports of the meeting as may be issued by the Commission.

Digitized by Google

diversities of language, two languages—French and English—were chosen by vote, as the official languages of the assembly; so that all reports, transactions and publications of the commission have to be prepared, delivered, and printed in these two languages simultaneously. French was voted for, instead of German, because the French language was more generally known to, and used by, the delegates, than the German. A single language, had it been possible, would have been much easier to deal with officially; because there is necessarily great difficulty in obtaining strictly equivalent renderings of any statement or resolution in two languages simultaneously. So great is this difficulty of bilingual renderings, that any attempt to introduce a third official language, and so to maintain three mutually equivalent renderings of all the proceedings, would probably break down in failure.

The meeting of 1908 saw work commenced on international nomenclature or lists of equivalent electrotechnical terms in one or more pairs of languages. Incidentally, it was decided as a matter of practical necessity, that all the quantitative resolutions of the commission should be stated and published in the international metric system of weights and measures, non-metric countries being allowed to employ their local equivalents of such values in parentheses.

In August, 1910, an unofficial meeting of the commission was held at Brussels, at the invitation of the Belgian committee, and under the acting presidency of Professor Eric Gerard. Messrs. A. E. Kennelly and Charles F. Scott attended this meeting on behalf of the United States Committee, appointed by the American Institute of Electrical Engineers. Active discussion took place, and good progress was made, in several technical directions, namely:

(1) International electrotechnical nomenclature and terminology.

(2) International symbols.

(3) International rating of machines.

The American Committee also reported the vote of the A. I. E. E., taken at the Jefferson convention, June, 1910, to refer to the commission the question of the direction of phase advance in alternating-current vector diagrams, for an international decision. The meeting accepted the proposition, and referred the question to all the national committees for consideration, and report at the next meeting.

Digitized by Google

It had been proposed to hold the next meeting at Berlin in 1911; but, in view of the proposal to hold an International Electrotechnical Congress at Turin in 1911, in connection with the Turin-Rome Exhibition, the German committee postponed its invitation, and the Italian committee's invitation was then accepted, to hold the next meeting of the Commission at Turin, in connection with the date of the Congress.

During the year 1910-1911, the central office in London circulated the questions raised at the Brussels meeting among the various national committees. The report of the Brussels meeting was published* in the PROCEEDINGS of the A. I. E. E., and the American committee reported the actions at Brussels to the Board of Directors of the A. I. E. E.

At the date of the Turin meeting of the Commission, the following countries had organized national committees of the Commission, sharing alike annually in the expenses of the Commission:

(1) Austria
(2) Belgium
(3) Brazil
(4) Canada
(5) Chile
(6) Denmark
(7) France
(8) Germany
(9) Great Britain
(10) Holland
(11) Hungary
(12) India (British)
(13) Italy
(14) Japan
(15) Mexico
(16) Spain
(17) Sweden
(18) Switzerland
(19) United States
(20) Uruguay

In some of these countries, such as British India, the committee is appointed by the government alone. In others, such as the United States, it is appointed by a single dominant electrotechnical Institution. In others, such as France, it is appointed by a number of electrotechnical societies, in coöperation. In all cases, however, the central office of the Commission recognizes and communicates solely with the local committee of each country, to the exclusion of any societies or institutions in that country. In other words, a national committee is organized in each country by the electrotechnical forces resident therein; but once the national committee is formed to represent that country, the central office deals exclusively with the committee, and communicates with that country through no other channel.

THE TURIN MEETING

The attendance at the Turin meeting by National Committees and their delegates was as follows:

*PROCEEDINGS of the A. I. E. E., December 1910, pages 10-11.

Digitized by Google

President of the Commission, Dr. Elihu Thomson.

Belgium. MM. Armand Halleux, G. A. L'Hoest, E. Gevaert, O. De Bast (secretary).

British Indian Government. M. F. H. Meares, Government Delegate.

Canada. Professor L. W. Gill.

Denmark. M. S. A. Faber, Professor Absalon Larsen (secretary).

Ecuador. Sr. Richard Muller, Professor of Electrical Engineering at University of Quito.

France. MM. R. V. Picou (President), H. Armagnat, P. Boucherot, E. Brunswick, M. J. Blondin, Ch. David (secretary), Paul Janet, F. Laporte (Adjunct Secretary), R. Legouez, G. Roux.

Germany. Herr Professor Dr. E. Budde (President) President of the Verband Deutscher Elektrotechniker, Herr Georg Dettmar (Secretary), Herr Geh. Ober Postrat Professor Dr. D. K. Strecker, President of the Committee on Units and Symbols of the Verband Deutscher Electrotechniker.

Great Britain. MM. Alexander Siemens (President), British Government Delegate, W. Duddell, F. R. S., Major W. A. J. O'Meara, C.M.G., C.B., British Government Delegate, M. R. K. Gray, Dr. Silvanus P. Thompson F.R.S. British Government Delegate, Professor T. Mather, M. P. F. Rowell (Secretary)

Holland. Professor Clarence Feldmann, President of the Electrical Section of the Dutch Society of Engineers. M. L. M. Barnet Lyon.

Hungary. Professor Dr. Moritz de Hoor-Tempes.

Italy. Professor Luigi Lombardi (President), President of the Associazione Elettrotecnica Italiana, Signor C. Clerici, Professor Guido Grassi, Signor E. Jona, Signor C. Montu, Parliamentary Deputy, Signor G. Semenza (Secretary), Signor P. Verole.

Japan. Professor Dr. A. Oya.

Mexico. Senor. Alfonso Castello.

Panama. The Consul of Panama at Turin.

Portugal. Il Barone Nasi, the Portuguese Consul at Turin.

Spain. Senor Don Luis de la Peña.

Sweden. MM. C. A. Rossander (President), E. C. Ericson (Secretary).

Switzerland. M. le Professor J. Landry (Secretary), K. Tauber.

United States. MM. C. O. Mailloux (President) U. S. Government Delegate, Gano Dunn, President of the American Institute of Electrical Engineers and U. S. Gov. Delegate, Dr. A. E. Kennelly (Secretary), Dr. Clayton H. Sharp.

GENERAL OFFICERS OF THE COMMISSION

Colonel R. E. Crompton, C.B., (Honorary Secretary), M. C. leMaistre, General Secretary, M. E. Litton, Assistant.

Nineteen countries, and eleven languages, were thus represented by 51 delegates, including the Presidents of the American, Dutch, German and Italian Institutions of electrical engineers.

The meetings at Turin were held in the handsome council chamber of the Provincial Palace of the Prefecture.

Digitized by Google

Official First Session, September 7th

At the first meeting, on September 7, after a reception by President Elihu Thomson, an address of welcome was given by His Excellency Signor Calissano, Italian Minister of Posts and Telegraphs. President Thomson then read an address, in which he complimented the influence of Italian genius upon the philosophy science and art of the world, and offered the congratulations of the Commission to the Italian nation on the fiftieth anniversary of its political union. He called attention to the growth and development of the Commission, the importance of its work, and the desirability of appointing various international sub-committees to carry on the work during the interim periods between successive meetings. This suggestion was very cordially received by the assembly.

After the report of Honorary Secretary Colonel Crompton, indicating the recent progress of the Commission, an election was held for officers of the ensuing period. M. Picou, the President of the French Committee, indicated the importance of Dr. Budde's past services to electrotechnics and to the Commission. He moved that Dr. E. Budde, the President of the German Committee, and of the Verband Deutscher Elektrotechniker, should be elected as President of the Commission, to succeed President Elihu Thomson. This motion was carried unanimously with acclamation. The Honorary Secretary and General Secretary were reappointed also with acclamation. Professor Lombardi was also unanimously elected to preside over the unofficial meetings, on September 8 and 9. After an official photograph of the assembly had been taken, the meeting adjourned.

Unofficial Second Session, September 8

At the unofficial meeting of the 8th, the first matter considered was international nomenclature. A subcommittee of one delegate from each of the countries—Belgium, France, Germany and Great Britain,—had been charged at the Brussels meeting, with the preparation of a report on this subject, and had met, earlier in the year, at Cologne. This sub-committee presented a list of 56 electrotechnical terms in general use, in connection with dynamo-electric machinery, drawn up in English and French, with their respective definitions in those official languages.

It may be said that it has hitherto been the policy of the

Digitized by Google

American Committee to leave nomenclature in the English language to their confrères in Great Britain, rather than to attempt a separate American nomenclature. In cases, however, where the American usage of a term differed appreciably from the British usage, notice of the fact was sent to the British Committee, which had then proceeded either to find a modification in terms suitable to the engineers of both countries; or to specify the distinction between the respective usages.

After some discussion, the report of the sub-committee was accepted, and provisionally adopted, by the meeting; with an order to print the same in both alphabetical and logical orders. A subcommittee on nomenclature consisting of one delegate from the British, French and German committees, was then voted, to continue the work, and to report at the next meeting of the Commission. The Danish and Spanish committees were especially invited to send delegates to follow the work of this subcommittee. Delegates from any or all national committees were held to be free to attend the meetings of this or other special subcommittees. The central office was, however, to arrange solely with the special subcommittee members for the dates of their meetings, the national committees being then informed of the dates selected.

The French committee submitted printed copies of its " Vocabulaire Electrotechnique " of 323 electrotechnical French terms, and their definitions in French, a task executed with a view to assisting in the work of the I. E. C.

The British committee also submitted printed copies of its latest work on nomenclature " Terms commencing with the letters F to M " being a list of 132 English terms in alphabetical order, with their English definitions, and also with unofficial definitions in French.

International Symbols. The report of the Brussels conference on symbols was then taken up. This report had been printed, and circulated among the various national committees, for nearly a year. The proposals were, after considerable discussion, adopted provisionally in the following form:

1. Instantaneous values of electrical quantities which vary with the time are to be represented by small letters.

2. Virtual or constant values of electrical quantities to be represented by capital letters.

3. Maximum values of periodic electrical quantities to be represented by capital letters followed by the subscript " m ".

Digitized by Google

4. Magnetic quantities, constant or variable, to be represented either by capital script, Gothic, heavy-faced, or other special type.

5. Maximum values of magnetic quantities to be represented either by capital script, Gothic, heavy-faced, or other special type, followed by the subscript " m ".

6. The following quantities to be represented by the following letters:

Electromotive force	E, e
Electric quantity	Q, q
Self-inductance*	$\mathfrak{L}$, $\mathbf{L}$ †
Magnetic force	$\mathfrak{H}$, $\mathbf{H}$ †
Magnetic flux density	$\mathfrak{B}$, $\mathbf{B}$ †
Length	L, l
Mass	M, m
Time	T, t

Dr. Budde, in the name of the German committee, and Mr. Alexander Siemens, in the name of the British Committee, proposed the definite adoption of the letters I, E and R to represent, respectively, the current, the electromotive force, and the resistance, in the simple algebraical expression for Ohm's law. This proposition was unanimously adopted.

M. Picou proposed, and Dr. Feldmann seconded, the proposition that in questions relating to alternating currents, the term " reactive power " be adopted to designate the quantity $U I \sin \phi$ where U is the virtual alternating potential difference, I the virtual current, and ϕ the difference of phase between them. This proposition was adopted.

A subcommittee consisting of one member from each of the following countries was appointed, to continue the study of the question of international symbols.

Belgium, France, Germany, Great Britain, Holland, Italy, Spain, Switzerland, United States.

Certain supplementary propositions of the French committee were referred to this subcommittee for consideration, and, at the suggestion of Mr. Feldmann, the question of special terms of a similar nature to " reactive power " was also referred to this subcommittee.

Summing up then the action of the assembly on symbols, the

*Coefficient of self-induction. †See Articles 4 and 5 as to Font.

Digitized by Google

recommendations of the Brussels conference were not only provisionally adopted, with minor amendments; *i.e.* adopted subject to possible revision, in detail, at some future commission meeting, but, owing to the loyal international coöperation of Germany and Great Britain, an international symbolic statement was definitely adopted for Ohm's law.

UNOFFICIAL THIRD SESSION, SEPTEMBER 9

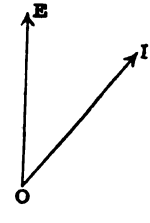
Diagrams for Alternating-Current Quantities. The question as to the direction of phase advance in the graphic representation of alternating-current quantities was taken up, as proposed by the Brussels conference, and in pursuance of the action originally taken by the American Institute of Electrical Engineers at its Jefferson Convention in 1910.

After a brief discussion, in which unanimity of opinion was manifested, it was moved by Professor S. P. Thompson, that the direction of phase advance should be in the counter-clockwise direction, as originally taken by Dr. Fleming. The following proposition was then unanimously adopted.

In the graphical representation of alternating electric and magnetic quantities, advance in phase shall be represented in the counter-clockwise direction.

NOTE.—In consequence, the impedance of a reactive coil, of resistance R, and inductance L, is $R+\sqrt{-1}\,L\,\omega$, and that of a condenser of capacity C, is $\frac{1}{\sqrt{-1}\,C\,\omega}$, where ω is equal to $2\,\pi\times$frequency.

It follows also that the diagram herewith represents the phase relations in a simple alternating-current circuit containing an impressed electromotive force $O\,E$ and a lagging current $O\,I$.



Summing up, then, the action of the assembly concerning alternating-current diagrams, or so-called vector diagrams, there was complete unanimity of opinion among all of the national committees, after a year of consideration for the subject, that the order of advance in phase in such diagrams should be counter-clockwise. All reference to the methods for deriving such diagrams was carefully avoided. That is to say, the question as to whether a "crank diagram", or a polar "time diagram", should be used, was not entered into, and only the relations of the

Digitized by Google

final vector-diagram were discussed. This leaves to engineers entire freedom to arrive at the internationally standardized vector diagram in any desired manner.

Ratings of Electrical Machinery and Apparatus. The propositions of the Brussels conference in regard to rating were adopted without modification as follows:

1. The output of electric generators is defined as the electric power available at the terminals.

2. The output of electric motors is defined as the mechanical power available at the shaft.

3. Both the electric and mechanical powers to be expressed in international watts.

A subcommittee consisting of one member from each of the following national committees was appointed to study the subject of the international rating of electrical machinery and apparatus:

Belgium, France, Germany, Great Britain, Italy, Sweden, Switzerland, United States.

Professor Elihu Thomson drew attention to a printed document " Extract from the Rules of various countries in reference to the rating of electrical machinery," published by the central office. This work, the value of which he was glad to recognize, would be likely to prove of great utility to the subcommittee.

In the name of the Italian committee, Mr. Jona presented a report dealing with this subject and especially with the question of prime movers, when closely related to electrical machinery.

The report was referred to the special committee, with instructions to give most careful consideration to the proposals of the Italian committee.

The national committees were requested to put themselves into communication with the technical societies of their respective countries, in order to facilitate the work of the Commission.

Summing up then the actions of the assembly in regard to international rating, although but little has yet been accomplished in this direction; yet the special subcommittee is now in a fair way to accomplish much, that has hitherto been impossible owing to differences of language, of national customs, of construction, and of viewpoint.

Future Meetings of the I. E. C.

The proposition of Signor Lombardi and Mr. Alexander Siemens, that the next official meeting of the I. E. C. be held

Digitized by Google

at Berlin, in 1913, was adopted, the exact date to be fixed by the central office, after consultation with the national committees. An unofficial meeting may be arranged in the meantime, if necessary.

Mr. Gano Dunn, as President of the A. I. E. E., cordially invited the I. E. C. to hold an official meeting at San Francisco, in 1915, on the occasion of the Panama Pacific Exposition, to be held in celebration of the opening of the Panama Canal. He announced that the A. I. E. E. was desirous of holding, at the same time, an International Electrical Congress, that the Board of Directors of the A. I. E. E. had already taken official action, had passed resolutions authorizing the Congress, and had instructed him to appoint a Committee on Organization, provided that an expression of opinion favorable to the holding of such a Congress were obtained from the I. E. C. at its meeting in Turin.

The meeting thanked Mr. Gano Dunn for the very cordial invitation of the A. I. E. E., and on the proposition of Mr. Feldmann, seconded by Mr. Duddell, adopted the following resolution:

"The I. E. C. expresses its willingness to hold an official meeting at San Francisco in 1915, and instructs the Central Office, on the request of the A. I. E. E., to coöperate with it in the organization of the International Electrical Congress in San Francisco at the same time."

As will be noted later, in relation to the Council Meeting of September 13, the I. E. C. undertook, at the request of the International Electrical Congress of Turin, the task of assigning and appointing future International Electrotechnical Congresses, in so far as concerns their times and places of meeting, so that the invitation of the A. I. E. E., as extended through Mr. Gano Dunn of the American Committee, was accepted in its entirety, both as to the holding of a meeting of the I. E. C., and of an International Electrotechnical Congress, at San Francisco, in 1915.

Illuminating Engineering and Technology

The Honorary Secretary of the Illuminating Engineering Society of London, Mr. Leon Gaster, personally invited to attend the meeting of the Commission, raised the question of the Commission studying the terms employed in matters of illumination, and requested that the national committees put themselves in communication with the Societies dealing with these questions in their respective countries.

Digitized by Google

Dr. Kennelly, speaking as President of the Illuminating Engineering Society of the United States, and Dr. Clayton H. Sharp, as a Past President, favored this idea, and the meeting expressed an opinion favorable to the suggestion.

Official Fourth Session, Plenary Meeting, September 11

At the plenary meeting of September 11, the various resolutions of the unofficial meetings on the 8th and 9th, were presented in writing, were read over in both of the official languages, and were formally voted without dissent. Many of these resolutions have been quoted at large, in this report.

Council Meeting of the I. E. C., September 13

The council of the I. E. C. is a species of executive committee, to which, by statute, the affairs of the Commission are entrusted, when no plenary meeting is in session. It consists of the President of the Commission, the Honorary Secretary, the Presidents of the various National Committees, and one additional delegate from each national committee. At this meeting, the communication was received from the International Electrotechnical Congress of Turin, to the effect that in view of the authority, permanence, and international organization of the I. E. C., the latter body was especially qualified to determine the relations between succeeding international electrotechnical congresses. The said Commission was therefore requested to undertake the task of organizing such congresses in future, in so far as relates to their times and places of convention, the details of organization being referred in each case to the particular committee and country in which the congress is to be held.

The council expressed its thanks to the congress, and undertook to comply with the request.

The meeting then adjourned, after passing votes of thanks to the officers of the Commission, and to their hosts, Professor Lombardi and the Italian Committee.

Social Features of the Commission Meeting

Although the sessions of the I. E. C. occupied the working hours of the days on which they occurred; yet the official and technical duties of the delegates were delightfully relieved by the cordial and assiduous attentions of their Italian hosts, who spared no pains to make the visit to Turin memorable for social pleasure as well as for electrotechnical accomplishment. The Italian committee held a banquet in honor of the delegates on

Digitized by Google

September 9, at which mutual toasts and congratulations were offered on the success of the meetings. At this banquet, a souvenir of the convention, in the form of a Japanese work of Art, was presented to the retiring President Professor Elihu Thomson, by a number of the delegates, who desired to testify their appreciation of the valuable services he had rendered to the commission during his term of office. Colonel Crompton acted as Master of the Ceremonies during this presentation.

Over and above the official resolutions adopted by the Commission, the Turin meeting brought about very successful results in active and cordial coöperation, which are bound to manifest themselves in the actions of the standing subcommittees. The real requisite in any international undertaking is cordial coöperation, without which all endeavors may be nugatory, but with which success becomes assured. To the labors of the permanent staff of the Commission, its Honorary and General Secretaries, this spirit of cordiality is largely due, aided by President Thomson, and the Italian Committee. President Mailloux of the American Committee, moreover, gave most valuable service to this, as to past meetings, of the I. E. C., by his very unusual linguistic abilities. Although, theoretically, any delegate can share in the work of the meetings, who can speak either English or French; yet, practically, no delegate can take an active part in the proceedings, who is not familiar with both these languages. Mr. Mailloux being thoroughly well acquainted with the German, Spanish, and Italian languages, besides English and French, has on many occasions been able to bring about unity of thought and action among delegates of different countries, which might otherwise have been impossible.

In conclusion, electrical engineers all over the world, thanks to the work of the I. E. C., now possess an internationally ratified symbolic expression of Ohm's law, a list of other international symbols, a good start toward international rating of machinery, a good nucleus of official international electrotechnical nomenclature, and an international decision on the long debated question of phase rotation in alternating-current vector diagrams. Moreover, largely owing to the personal incentive of President Dunn of the American Institute of Electrical Engineers, the way has been officially paved for holding a commission meeting and a congress at San Francisco in 1915.

A. E. KENNELLY,
Secretary of U. S. National Committee.

Digitized by Google

Report to the American Institute of Electrical Engineers from its Delegation to the Congress, and subject to the official report of the Congress.

Copyright 1911. By A. I. E. E.

THE INTERNATIONAL ELECTROTECHNICAL CONGRESS OF TURIN*

Historical Outline

Information was laid before the American Institute of Electrical Engineers in 1910, that an International Congress of the Applications of Electricity would be held, at Turin, from the 10th to the 17th of September, 1911, under the auspices of the Associazione Electrotecnica Italiana (A. E. I.) and of the Italian Electrotechnical Committee of the I. E. C., in connection with the Turin-Rome International Industrial Exhibition.

International Electrical Congresses since the year 1900, inclusive, have been held as follows:

In 1900, at Paris, in connection with the Paris Exposition Universelle.

In 1904, at St. Louis, in connection with the World's Fair of St. Louis.

In 1908, at Marseilles, in connection with the Marseilles Exhibition.

In connection with the Congresses of 1900 and 1904, there had been appointed a chamber of Government Delegates, charged with the work of international electrotechnical agreement, in addition to the Congress at large, in which papers were read and discussed. In pursuance of a vote taken in the chamber of Delegates at the St. Louis Congress of 1904, the duties of such Chambers were relegated to a special international commission. This International Electrotechnical Commission—the I. E. C.—was formed with a permanent organization in 1906, and no

*A report to the Board of Directors of the A. I. E. E. from its Delegation to the Turin Congress, and subject to such official reports as the Congress may publish.

Digitized by Google

chamber of government delegates was formed at the Marseilles Congress.

In connection with the Turin Congress, it was arranged that a meeting of the I. E. C. should be held at Turin, immediately before (7th–12th Sept.) the convention of the Congress.

Organization of the Turin Congress

The Turin Congress was organized under (1) A Committee of Honor. (2) An Organizing Committee. (3) An Executive Committee nominated by the General Council of the A. E. I.

(1) The Committee of Honor was headed by H. R. H. the Duke Degli Abruzzi, and included 28 members, among whom were Professor Elihu Thomson, President of the I. E. C., Colonel Crompton, Honorary Secretary of the I. E. C., and Signor Antonio Pacinotti, Honorary President of the A. E. I.

(2) The Committee of Organization comprised 30 members as follows:

President Professor Luigi Lombardi, President of the A. E. I.

Vice-President Professor Guido Grassi, President of the Turin Section of the A. E. I.

Secretaries, Signori C. A. Curti, and G. Semenza.

Members, Messrs. M. Ascoli, E. Jona, Q. M. Calatabiano, L. Amaduzzi, F. Fusco, G. Cesare, A. Vivarelli, A. Panzarasa, M. Pizzuti, G. Amati, S. Pagliani, C. Esterle, L. Pontiggia, L. A. Herdt, C. A. Rossander, A. Siemens, R. V. Picou, M. G. A. Hagemann, E. Budde, E. Gerard, O. T. Blathy, J. Alonso y Millan, F. Drexler, C. Feldmann, K. P. Tauber, C. Zipernowsky, H. Armagnat.

A sub-committee for the United States was formed as follows: President, J. W. Lieb, Jr.; Members, D. C. Jackson, A. E. Kennelly, C. O. Mailloux, T. C. Martin, H. G. Stott, S. W. Stratton.

(3) The Executive Committee comprised 23 members as follow:

President Professor Guido Grassi.

Secretaries Signori G. Lignana, and F. Nizza.

Treasurer, A. Luino.

Members, Messrs. E. Morelli, V. Tedeschi, C. Montu, O. Trossarelli, E. Soleri, P. Forster, A. Rostain, G. G. Ponti, R. Arnò, V. Treves, A. Miolati, L. Ferraris, T. Chiesa, P. Prat, G. Schultz, G. Bisazza, E. Lauchard, E. De-Benedetti, R. Pinna.

Digitized by Google

The technical work of the Congress was divided among eight sections. Thirty-one specific official topics were selected, and announced in advance, by the Committee of Organization, and papers or reports on these topics were secured, in advance, from as many authors in 10 countries: *viz.*, Austria, Belgium, Denmark, France, Germany, Great Britain, Italy, Sweden, Switzerland and the United States.

In addition to the officially prepared papers or reports on specified topics, about fifty independently offered papers on various subjects were accepted by the Organizing Committee.

The subscription for membership in the Congress was fixed at 25 Lire ($5), entitling the holder to all the publications and privileges of the organization. A reduced subscription of 10 Lire ($2), entitled a holder to attend the technical meetings, as a listener, but to the exclusion of all publications or privileges.

The technical meetings of the Congress were of two kinds—plenary and sectional. There were three plenary meetings, one of opening, the second, intermediate, and the third of closing. The sectional meetings were for the reading and discussion of papers. They took place between the first and third plenary meetings.

Four official languages were selected for the reception of papers and reports: namely, French, Italian, English and German. All papers in Italian, English, or German, were required to be accompanied by a summary in French. The official bulletins of the Congress were issued daily in Italian and French. Votes and resolutions in plenary meetings were presented in both Italian and French. When a single language was employed as a vehicle of discussion, it was most frequently the French; although discussions were admitted in any of the four official languages. All the technical meetings of the Congress were held at its headquarters—the Reale Politecnico, via Ospedale, Turin—a large technical college granting degrees, following five-year courses of instruction in civil engineering, mechanical engineering, (including electrical engineering), chemical engineering, and architecture.

The greater number of the reports and papers communicated to the Congress were printed, and circulated in advance of each day's sessions.

About 450 full-membership adhesions were published before the close of the Congress, and the total registration of members in both classes amounted to about 650.

Digitized by Google

The following is a list of the foreign government delegates and of the delegates from technical institutions.

Representatives of Foreign Governments

Austria. Messrs. Alfredo Graf, Alfredo Deinlein.
Belgium. Messrs. Ernest Gerard, D. L'Hoest, l'Ing. Colson, Eugene Gevaert.
Denmark. Ing. Joh. Rasch.
France. Messrs. M. Barbillion, Swyngedauw.
Japan. Mr. Atsushi Oya.
British India. J. W. Meares.
Great Britain. Major W. A. J. O'Meara, Dr. R. T. Glazebrook, A. Siemens, Dr. S. P. Thompson.
Luxemburg. Mr. Charles Eydt.
Mexico. Ing. Alfonso Castello.
Portugal. Baron Nasi di Cossombrato.
Ecuador. Messrs. Richard Muller, Alfredo Gerard.
Russia. Messrs. Pierre Ossadtchy, Colonel de Mouromtzew.
Spain. Messrs. Alfredo Lasala, Jose Abbad Boned, Luis De La Pena, Manuel de Justo y Sanches Blanco.
United States. Messrs. Gano Dunn, C. O. Mailloux, H. B. Brooks.
Switzerland. Messrs. Gustavo Sulzberger, Christian Brunnschweiler, E. Vanoni.
Hungary. Frederic Koromzay.

Delegates of Technical Societies

Austria.
Elektrotechnischer Verein, Vienna: Ing. Alfredo Grünhut.
Osterreichischer Ingenieur und Architekten Verein di Vienna: Ing. Alfredo Deinlein.

Belgium.
Association des Ingenieurs Electriciens sortis de l'Institut Montefiore de Liege: Omer de Bast.

Denmark.
Den Tekniske Forening, Copenhagen: P. O. Pedersen.
Dansk Ingenierforening, Copenhagen: P. O. Pedersen Ing. Valdemar Poulsen.

France.
Société Internationale des Electriciens de Paris: Boucherot, Armagnat, Brunswick, Janet, Legouez, Blondin.
Syndicat Professionnel des Usines d'Electricité de Paris: Eschwège, Legouez, Brylinski, Berthelot.
Société des Ingénieurs Civils de Paris: Paul Leclerc.
Société des Agriculteurs de France: Paul Leclerc.

Germany.
Verband Deutscher Electrotechniker: Prof. Dr. E. Budde, G. Dettmar.

Digitized by Google

Great Britain.

The Institution of Electrical Engineers: S. Z. De Ferranti, Colonel R. E. Crompton, Dr. R. T. Glazebrook, R. Haye Gray, A. Siemens, S. P. Thompson, W. Duddell, W. A. J. O'Meara, R. Hammond, Æ. H. Patchell.

The Illuminating Engineering Society: Prof. S. P. Thompson, Leon Gaster, R. J. Wallis-Jones, Justuk Eck.

The Institution of Mechanical Engineers: W. H. Patchell.

Electrical Section, London Chamber of Commerce: Leon Gaster, Charles P. Sparks, A. Bruce Anderson.

Italy.

Accademia delle Scienze Fisiche e Matematiche di Napoli: Prof. Guido Grassi.

Collegio degli Ingegneri ed Architetti di Milano: Ing. Denti Eugenio.

Collegio Ingegneri ed Architetti di Napoli: Ing. G. D. Cangia.

Associazione Amichevole fra gli Ingegneri ex-Allievi della Scuola di Torino: Ing. Comm. Oreste Lattes.

Reale Istituto Lombardo di Scienze e Lettere di Milano: Prof. Riccardo Arno, Prof. Francesco Grassi.

Societa Ingegneri ed Architetti Italiani di Roma: Ing. Prof. Giuseppe Revessi.

Collegio Veneto degli Ingegneri di Venezia: Ing. Cav. Filippo Danioni.

Collegio Nazionale degli Ingegneri Ferroviari Italiani di Roma: Comm. Lattes Oreste.

Collegio Ingegneri ed Architetti Pugliesi di Bari: Ing. Nicola Stea.

Associazione Elettrotecnica Italiana:

Sezione di Roma: Prof. Comm. Guglielmo Mengarini, Ing. Ulisse Del Buono.

Sezione di Genova: Cav. Vittorio Capellini.

Holland.

Institut van Ingenieurs d'Olanda: L. M. Barnet-Lyon Clarence Feldmann.

Argentine Republic.

Sociedad Cientifica Argentina di Buenos Ayres: Dr. Ing. Angel Gallardo, Ing. Domingo Selva.

Russia. Sezione elettrotecnica della Societa Imperiale Russa di Pietroburgo: Prof. M. de Chatelain.

Istituto elettrotecnico di Pietroburgo: Prof. Graftio.

Spain.

Sociedad Espanola de Fisica y Quimica di Madrid: A. Gabasso, Luis de la Pena, Enrique Hauser.

Instituto de Ingenieros Civiles di Madrid: Ing. Luis de la Pena, Ing. Don Antonio Gonzales Echorte.

Switzerland.

Physikalische Gesellschaft Zurich: Dr. H. Behn-Eschenburg, Dr. Ing. S. Guggenheim.

Digitized by Google

United States.

American Institute of Electrical Engineers: Prof. E.Thomson, C. O. Mailloux, Dr. A. E. Kennelly, Gano Dunn, Prof. C. A. Adams, H. B. Brooks, E. P. Burch, G. Faccioli, Etienne de Fodor, R. O. Heinrich, Francis Jehl, Hirayoshi Oshima, C. H. Sharp, J. F. Stevens, Philip Torchio.

Association of Edison Illuminating Companies: Philip Torchio.

American Electrochemical Society: C. O. Mailloux.

Franklin Institute: G. Faccioli, A. E. Kennelly.

Plenary Meetings

(1) The opening plenary meeting took place at 10:30 a.m. on Sunday, September 10. An address of welcome was read by Senator P. Boselli, President of the Royal Academy of Sciences at Turin, in the presence of a number of official delegates. This was followed by an address by Professor Luigi Lombardi, who, in welcoming the members, set forth the hopes and purposes of the Congress, as well as the arrangements made for showing the most interesting electrotechnical plants, exhibits, and features of importance to visitors. A fine address was then delivered by the Minister of Posts and Telegraphs Signor Calissano, who was elected honorary president of the Congress. The following elections of officers were then made:

President—Prof. Luigi Lombardi, President of the A. E. I.

Vice-Presidents—Prof. Guido Grassi.
Ing. Emanuele Jona.

General Secretary—Ing. Guido Semenza.

Honorary Vice-Presidents—Antonio Pacinotti for Italy.
Silvanus P. Thompson and Alexander Siemens for England.
Gano Dunn for the United States.
Paul Janet for France.
Karl Strecker for Germany.
Alfred Graf for Austro-Hungary.
Pierre Ossactchy for Russia.
Gustave L'Hoest for Belgium.
Behn-Eschenburg for Switzerland.
De La Pena for Spain.
Poulsen for Denmark.

Digitized by Google

The following Section officers were then elected, after which the plenary meeting adjourned.

Section	Subject	President	Vice-Presidents	Secretary
I.	Electrical Machines and Transformers.	Boucherot (France)	Morelli (Italy) Feldmann (Holland)	C. Palestrino
II.	Electrical Installations and Networks	De Bast (Belgium)	Ferraris (Italy) Landry (Switzerland)	Del Buono Boccardo
III.	Instruments, Apparatus and Switching Devices.	Kennelly (U. S. A.)	Dina (Italy) Armagnat (France)	Emmanueli Barbagelata
IV.	Lighting and Heating by Electricity.	Rossander (Sweden)	Mengarini (Italy) Sharp (U. S. A.)	Danioni
V.	Electrical Traction and Propulsion.	Mailloux (U. S. A.)	Sartori (Italy) Barnet Lyon (Holland)	Fenzi Ponti
VI.	Telegraphy and Telephony.	O'Meara (Grt. Britain)	Larsen (Denmark) Di Pirro (Italy)	Bellini
VII.	Accumulators, Electro-Chemistry, Electro-metallurgy and other applications.	Beckmann (Germany)	Miolati (Italy) Duddell (Grt. Britain) Rumi (Italy)	
VIII.	Tariffs, Taxation and Legislation in regard to the distribution of electrical energy.	Arno (Italy)	Dettmar (Germany) Bonghi (Italy)	Botto Guiletti

(2) *The Intermediate Plenary Meeting of September* 13. After some discussion by President Lombardi on the subject of the organization of future electrotechnical congresses, the following resolution was put by M. Clarence Feldmann (Holland), and carried unanimously, after being seconded by Messrs. Boucherot (France), S. P. Thompson (Great Britain), Mailloux (U. S. A.), L'Hoest (Belgium), Strecker (Germany), De Chatelain (Russia), and Grassi (Italy).

Whereas, the provisional committee appointed by the International Electrotechnical Congress of Marseilles for the purpose of forming a permanent international committee of organization for electrotechnical congresses has made no report.

and *Whereas*, The International Electrotechnical Commission, permanently organized since 1906, is by its position, authority and statutes especially adapted to be the permanent organization for securing the connecting link between international electrotechnical congresses and to give effect to their labors.

The International Electrotechnical Commission is requested to accept the task of organizing future electrotechnical Congresses so far as concerns their dates, places of meeting, and objects,

Digitized by Google

the details of the organization of each congress being confided to the electrotechnical committee of the country in which the congress is to be held, with the assistance of its technical societies, if necessary.

The meeting then adjourned.

The request was accepted by the Council of the I. E. C. on the 13th.

(3.) *The Closing Plenary Meeting of Saturday, September* 16. The following resolutions were presented to the plenary meeting after having been published in the official bulletin. All were adopted.

(1) From Section III.

The International Electrotechnical Congress of Turin compliments the American Institute of Electrical Engineers on the practice it has adopted of inserting in its publications the metric equivalent value, in parentheses, after each expression of values in English measures.

And since this procedure greatly facilitates the reading of these publications in all the countries using the metric system, while constituting a worthy example towards and in view of the much desired complete international unification of weights and measures.

Resolved, that the technical societies of all countries in which the metric system is not yet official, are invited to follow the above-mentioned example of the American Institute of Electrical Engineers.

This vote was carried with much acclamation.

(2) From Section IV.

The Congress favors the appointment of an International Commission for the general study of systems of illumination, and of all technical problems connected with illumination, proposing that the Illuminating Engineering Society of London be charged with the formation of this International Commission, placing itself for that purpose in communication with all other existing national and international photometric committees.

(3) From Section V.

The committee of the fifth section charged with the duty of examining the proposition of Mr. Mailloux concerning the definition and industrial determination of train acceleration reports as follows:

Whereas, in industrial traction, the speed of trains is always measured in kilometers per hour, (or in local equivalent values), and

Digitized by Google

Whereas, it is logical to start with such a definition of train velocity, in order to express the acceleration per second, and

Whereas, such definitions of train acceleration are invariably used in America, and are also largely used in other countries. *and*,

Whereas, a similar proposal has already been recommended favorably by the International Electrotechnical Congress of Marseilles (1908).

Resolved by this Congress that:

(1) Train accelerations be expressed in kilometers per hour per second.

(2) That the International Electrotechnical Commission be informed of this resolution.

(4) From Section VIII.

Two resolutions relating to political and fiscal questions of European rather than American interest.

(5) From certain individual members:

That the next International Electrotechnical Congress should form a section devoted to the subject of electrotechnical instruction.

Closing reports and addresses were then made by the President, the Section-Presidents and various government delegates, who expressed the general thanks of the assembly to the officers of the Congress, the President and Secretary, and the Italian committee for their attentions and courtesies during the exercises of the Congress.

The Congress than finally adjourned.

Meetings of the Sections

A list of the reports and papers presented as to the different sections is appended herewith. The contributions numbered 80 in all, from writers in 14 different countries, 11 contributions being presented from America.

Meetings in Honor of Senator Antonio Pacinotti, and of Professor Galileo Ferraris. A meeting of the A. E. I., attended by a large number of members of the Congress, was held on September 13, to celebrate the semi-centennial anniversary of his invention of the Pacinotti-ring dynamo-electric machine, the original model of which was displayed in the electrical department of the Turin Exhibition. The President of the A. E. I., Professor Lombardi, with a very appropriate address, delivered to Signor Pacinotti a handsomely framed and illumined parch-

Digitized by Google

ment, on which was reproduced, in miniature, the classic paper published by him on the dynamo-electric machine in " Il Nuovo Cimento " of 1865. An illuminated album accompanied the gift, containing the testimonial signatures of most of the members of the A. E. I., as well as of many Congress members.

Professors Mengarini and Silvanus P. Thomson expressed the admiration and respect of the electrotechnical world, both in Italy and abroad, for the work of the illustrious Italian scientist.

A brief and modest reply was made by Signor Pacinotti, which was enthusiastically received, after which the meeting adjourned.

At another hour, an unofficial gathering took place in the large public square, called the " Piazza Castello," at the foot of the monument erected to Galileo Ferraris, the well-known Turin scientist, teacher and electrician, who discovered and first applied the principal of the rotating magnetic field. Three wreaths were laid on the pedestal, one offered by the French delegation, another by the American delegation, and the third by the city of Frankfort on Maine.

The Mayor of Turin made an eloquent speech in tribute to the work of Ferraris, and responses were made by M. Ferdinand Meyer on behalf of the French electricians, Mr. Philip Torchio, on behalf of American electricians, and Mr. Hartmann of Hartmann & Brown, on behalf of the city of Frankfort.

Technical Visits. On Thursday September 14, an all-day trip was taken from Turin to Genoa and back, inspecting en route the " Giovi " lines and system. This is a three-phase electric railway, running from Busalla through Pontedecimo to Compasso. The locomotives are of European " Westinghouse " construction, supplied through overhead trolley lines with alternating currents at 3,000 volts pressure, at a frequency of 15 cycles per second. The locomotives are regenerative, and return power to the system when descending grades of 0.7 per cent or more.

Another visit was arranged for September 17 to Mont Cenis, where the Societ i delle Forze Idrauliche del Moncenisio has hydraulic plants that transmit three-phase power, at 30 kilovolts, to Turin and beyond, at a frequency of 50 cycles per second.

Entertainments. The social features of the Congress were prepared and carried out with great care by the Italian committee, each day being provided with some special social event. There was also a special committee of Italian ladies to meet the ladies

Digitized by Google

of the guests, and arrange for their entertainment. The prevailing pleasant weather aided the entertainment committees on all occasions.

On the 10th, a dinner was given to the official delegations at the Superga, on the top of a hill 420 meters in height, about 10 kilometers north of Turin, with a rare and magnificent view of the Piedmontese Alps. On the 11th, an evening reception was given to the Congress by the Turin Municipality at the Circolo degli Artisti. On the 12th, a dinner was given by the City of Turin to the official delegates of the Congress, and another dinner, at the Exposition was given to the Congress members on the 13th. A lunch was also given by the Italian Committee, to the American delegation, which will be memorable to all who attended it, for the charm of the occasion and the sentiments it elicited.

There can be no doubt that not only the Congress guests as a whole; but also the American guests in particular, are under many obligations to their Italian hosts at Turin for attentions and courtesies during their very pleasant visit. The hope was expressed by President Dunn of the A. I. E. E., that many of the members of the Italian Society would be able to attend the Congress of 1915 at San Francisco, under the auspices of the American Institute. Mr. C. O. Mailloux, as the President of the American Delegation had frequent occasion to use his well known linguistic abilities, not only at the Congress sessions; but also at the social reunions, where his speeches in French and Italian were much applauded.

Conclusions

The permanent results of the Turin Congress may be summarized as follows:

(1) The record of some 80 reports and papers with discussions on the same, destined to be published in due season by the Congress, and distributed among the members.

(2) The resolutions of the plenary sessions of the Congress which bring its conclusions to a focus. As already detailed these particularly contain:

(*a*) A provision for the regular convocation of future international electrotechnical congresses, by assigning them to the jurisdiction of the I. E. C.

(*b*) The adoption of the kilometer-per-hour-per-second as the industrial unit of train acceleration.

Digitized by Google

(*c*) A formal vote of thanks to the A. I. E. E. for its help to foreign engineers, in printing parenthetical metric equivalents.

(*d*) That an international illuminating-engineering commission should be formed.

(3) Over and above the records of the Congress, there remains with all the members who attended it, the wealth of memories and experiences derived from meeting confrères of other countries, and from a sympathetic insight into the solutions of the problems which confront them.

A. E. KENNELLY,
Secretary American Delegation.

LIST OF REPORTS AND PAPERS* PRESENTED BY SECTIONS

SECTION I

ELECTRICAL MACHINES AND TRANSFORMERS

Reports.

Dr. H. Behn-Eschenburg. Electrical and mechanical characteristics of modern generators.

Ing: G. P. Clerici. The problem of cooling transformers of medium size.

Dr. S. P. Thompson. Converters, rectifiers and motor-generators.

Paul Bunet. The problem of frequency transformation.

Ing: C. Sarli. Variable speed three-phase motors, with special reference to rolling mills.

Papers.

Dr. Hallo. Motor-converters.

Boucherot. Electromagnetic phenomena resulting from the sudden short-circuit of an alternator.

R. Legouez. Commutator motors.

SECTION II

INSTALLATIONS, CENTRAL STATIONS, SWITCHBOARDS, CONDUCTING LINES

Reports.

Philip Torchio. The selection of voltage and the construction of switchboards and of substations in large electric systems.

J. Grosselin. High-tension underground networks in metallic connection with overhead lines.

E. Ragonot. The construction and use of automatic circuit breakers.

G. Semenza. The synchronous operation of several central stations feeding the same network.

Papers.

S. Q. Hayes. Commercial Electrical apparatus for 100,000 volt service.

Ing: E. Solari. The extreme limits of high-tension employed in cables.

*The titles are here given in English when presented in another language.

Digitized by Google

Dr. Ing. Leon Lichtenstein. Recent experiments and tests on high-tension cables.

Dr. Osuke Asano. Progress in electrical installations in Japan.

Etienne de Fodor. The present state of the problem of sewage disposal in connection with electric stations.

J. Routin. Automatic regulation.

Dr. Ing. W. Weicker. Protection against over voltage on aerial lines, especially with suspension insulators.

E. Hubet Stockar. Aluminum for electrical conductors.

Paul Lecler. Electrotechnical applications to reinforced concrete.

SECTION III

INSTRUMENTS AND METHODS OF MEASUREMENT, PROTECTION OF INSTALLATIONS, MISCELLANEOUS

Reports.

G. Faccioli. High-tension switching phenomena.

Dr. C. H. Sharp. Electricity Meters, with special reference to different kinds of loads.

A. Durand. Electricity meters.

Papers.

Ing: Alberto Dina. The measurement of insulation-resistance in an alternating-current system during its operation.

Prof. Riccardo Arno. Watt-volt ampere meters.

Ingg. A. Barbagelata and L. Emanueli. Zero methods of alternating-current measurement.

Prof. G. Revessi. A contribution to the study of stray currents.

A. E. Kennelly. The rotating electric current field.

Vladimir Karapetoff. Some practical calculations of electrostatic fields.

Jules Neher. Multiple-rate electricity meter.

Dr. C. P. Steinmetz. The nature of electric transient phenomena.

Prof. E. E. F. Creighton. Protection of electric systems.

Ing. Alberto Dina. On methods of preventing internal over voltages.

Ing. Gino Campos. The propagation of oscillatory over voltages.

Ing. G. Martinez. Some new industrial alternating-current instruments.

J. L. Farny. On a new oscillographic process with the Braun tube.

M. de Chatelain. On a laboratory for the study of high-tension. currents up to 500 kilovolts.

G. Neuhaus. Protective relays.

SECTION IV

ILLUMINATION AND HEATING

Reports.

Prof. D. Wedding. The influence of incandescent and arc lamps on the illuminating industry.

C. A. Rossander. The present and future of electric heating.

Papers.

Ing. C. Herrgott. On the heating of textiles by electricity.

Dr. Ing. Monasch. Manufacture and operation of metallic-filament lamps.

Digitized by Google

Ing. Adolfo Hess. Practical results with a system of high tension intensive arc-lamps.
Leon Gaster. The international outlook in scientific illumination.
Dr. Luigi Pasqualini. Parabolic mirrors for electric arc projectors.
Prof. R. Swyngedauw. An electric heating apparatus using Foucault currents.

Section V
Electric Traction

Reports.

Ing. Giorgio Calzolari. Single phase and three phase traction on lines of heavy traffic.
Gustave L'Hoest. Overhead line construction on electric railroads.
Ing. Agostino Bezzi. Electric applications in submarine vessels.

Papers.

Ing. Guillaume Gyaros. Electric traction on suburban lines.
Dr. W. Kummer. On the development of single phase locomotives.
C. O. Mailloux. Electrification of railroads.

Section VI
Telegraphy and Telephony

Reports.

F. V. Jewett. Long distance telephony in America.
Dr. Giovanni di Pirro. Long distance telephony.
Dr. Valdemar Poulsen. Wireless telephony.
H. Milon. Automatic and semi-automatic telephonic systems.
Prof. P. O. Pedersen. Secrecy in radiotelegraphic communications.
Major W. A. J. O'Meara. The different systems of multiple telegraphy.

Papers.

Prof. A. Majorana Calatabiano. Wireless telephone research.
J. Erksine Murray. A definition of the efficiency of a wireless telegraph system.
Ing. Ettore Bellini. The Hertzian azimuth compass.

Section VII
Storage-cells, Electrochemistry, Electrometallurgy and other Applications

Reports.

Dr. H. Beckmann. The present state of the electric storage cell.
Ing. Remo Catani. The direct production of steel from its ores in the electric furnace.
Dr. Erlwein. The sterilization of water by electrical processes.
Paul Lecler. The distribution of electrical energy in farming.

Papers.

Dr. Sigm. Guggenheim. The electric results furnished by the chief induction furnaces of the steel industry.
Ing. Luigi De Andreis. The sterilization of water in the Rovigo aqueduct.
J. A. Montpellier. The technique of the electric storage-cell especially with reference to the iron-nickel cell.

Digitized by Google

Prof. Oscar Scarpa. On the sterilization of water by ultraviolet rays.

Dr. M. Recklinghausen. The sterilization of city water supplies by ultraviolet rays.

SECTION VIII

TARIFFS, LEGISLATION FOR AND TAXATION OF ELECTRIC SUPPLY

Reports.

Dr. A. Denzler. The government control of electricity meters.

Ing. G. G. Ponti. Rational methods for the commercial measurement of electric power.

Ing. Prof. Giuseppe Sartori. The problem of increasing the load factor of central stations.

Ing. Mario Bonghi. Comparative study of direct and indirect taxation of electricity in different countries.

Dr. H. Schreiber. Government regulations on the electric transmission of power.

E. C. Ericson. Government regulations on the electric transmission of power.

L. M. Barnet-Lyon. Government regulations on the electric transmission of power.

Papers.

Prof. Riccardo Arnò. A solution of the problem of a rational charge for electric energy.

Louis Prat. Mechanical problems in central stations.

Digitized by Google

Digitized by Google

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 12

December, 1911

Per Copy, $1.00
Per Year, $10.00

UNIVERSITY OF MINNESOTA
THE LIBRARY
D 14 1911
RECEIVED

CONTENTS

Section I. Notes and Comments

A. I. E. E. Meeting, New York, December 8, 1911, to be followed by a Smoker - - - - - - - 321
Resume of Business Transacted at Meeting of the Board of Directors of the A. I. E. E., held November 10, 1911 - - - - 321
Water Power Development - - - - - - 323
Von Helmholtz Bust Presentation - - - - - 324
A. I. E. E. Meeting in New York, November 10, 1911 - - - - 331
Panama Trip - - - - - - - - 332
Future Section Meetings - - - - - - 333
Associates Elected November 10, 1911 - - - - - 334
Applications for Election - - - - - - 335
Recommended for Transfer - - - - - 336
Students Enrolled November 10, 1911 - - - - 336
The American Society of Mechanical Engineers - - - 338
Annual Meeting of the Chemical Engineers, Washington, D. C., December 20-22, 1911 - - - - - - - 338
Cost of and Rates for Electric Service - - - - - 339
The John Fritz Medal - - - - - - - 339
Past Section Meetings - - - - - - - 340
Past Branch Meetings - - - - - - - 344
Personal - - - - - - - - 347
Obituary - - - - - - - - 348
Library Accessions - - - - - - - 349

Section II. Papers, Discussions, and Reports

[For table of contents under this heading see page 359]

Index to Advertisements - - - - - - - iii

Copyright 1911, by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Permission is given to reprint any matter provided proper credit is given.

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

Digitized by Google

Seventeen New Electrical Books

THE PROPAGATION OF ELECTRIC CURRENTS.
In Telephone and Telegraph Conductors.
PROF. J. A. FLEMING, M. A., D. Sc., F.R.S.
330 Pages. 5½x9 Inches. Illustrated.
Net $3.00.

ELECTRIC TRACTION AND TRANSMISSION ENGINEERING.
PROF. S. SHELDON, A.M., Ph.D., D.Sc., and E. HAUSMANN, E.E., M.S.
Both of Brooklyn Polytechnic Institute.
317 Pages. 5½x8 Inches. 127 Illustrations.
Net $2.50.

CONTINUOUS CURRENT MACHINE DESIGN.
PROF. WILLIAM CRAMP, M.I.E.E.
260 Pages. 5½x8¾ Inches. 137 Illustrations.
Net $2.50.

ELECTRIC TRAINS.
H. M. HOBART, M. Inst. C.E.
220 Pages. 5½x8¾ Inches. 88 Illustrations.
Net $2.50.

THE DESIGN OF STATIC TRANSFORMERS.
H. M. HOBART, M. Inst., C. E.
190 Pages. 5½x8¾ Inches. 100 Illustrations.
Net $2.00.

ELECTRIC CENTRAL STATION DISTRIBUTION SYSTEMS.
Their Design and Construction.
H. B. GEAR, Assoc. A.I.E.E., and P. F. WILLIAMS, Assoc. A.I.E.E.
352 Pages. 6x9 Inches. 139 Illustrations.
Net $3.00.

A SHORT COURSE IN THE TESTING OF ELECTRICAL MACHINERY.
For Non-Electrical Students.
PROF. J. H. MORECROFT, Assoc. A.I.E.E., and P. W. HEHRE, both of Columbia Univ.
160 Pages. 6½x9½ Inches. 84 Illustrations.
Net $1.50.

DIRECT AND ALTERNATING CURRENT MANUAL.
PROF. FREDERICK BEDELL and C. A. PIERCE
Both of Cornell University.
Second Edition Enlarged.
360 Pages. 6x8¾ Inches. Illustrated.
Net $2.00.

SOLENOIDS, ELECTRO-MAGNETS AND ELECTRO-MAGNETIC WINDINGS.
CHAS. R. UNDERHILL, Assoc. Mem. A.I.E.E.
345 Pages. 5x8 In. Cloth. 210 Illustrations.
Net $2.00.

ELEMENTARY ELECTRICAL CALCULATIONS.
T. O'CONOR SLOANE.
314 Pages. 5½x8¼ Inches. Illustrated.
Net $2.00.

ELECTRIC POWER CONDUCTORS.
WM. A. DEL MAR, Assoc. Mem. A.I.E.E.
330 Pages. 5½x8 Inches. 69 Illustrations.
Net $2.00.

HYDROELECTRIC DEVELOPMENTS AND ENGINEERING.
FRANK KOESTER, Assoc Mem. A I E E
Mem Society of German Engineers (Berlin).
Author of "Steam-Electric Power Plants,"
475 Pages. 7½x10½ Inches. 500 Illustrations.
Net $5.00.

TOLL TELEPHONE PRACTICE
J BERNHARD THEISS and GUY A JOY.
With an introduction by F F Fowle.
About 400 Pages. 6x9 In. 268 Illustrations.
Probable Price $3.00.

MOTORS, SECONDARY BATTERIES, MEASURING INSTRUMENTS AND SWITCH GEAR.
S. K. BROADFOOT, A.M.I.E.E.
16 Illustrations. 100 Pages.
Net 75c.

MILL AND FACTORY WIRING.
R. G. DEVEY, A.M.I.E.E.
128 Illustrations. 200 Pages.
Net $1.00.

ELECTRICAL MINING INSTALLATIONS.
P. W. FREUDEMACHER, A.M.I.E.E.
35 Illustrations. 190 Pages.
Net $100.

ARC LAMPS AND ACCESSORY APPARATUS.
J. H. JOHNSON, A.M.I.E.E.
20 Illustrations. 140 Pages.
Net 75c.

D. VAN NOSTRAND COMPANY
Publishers and Booksellers
23 Murray and 27 Warren Streets - New York
Descriptive Circulars Sent On Request

Digitized by Google

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies.
All other countries $12.00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **December, 1911** No. 12

A. I. E. E. Meeting, New York, December 8, 1911, to be Followed by a Smoker.

The two hundred and sixty-sixth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York, on Friday, December 8, 1911, at 8:15 p.m. A paper on "Methods of Varying Speeds of Alternating-Current Motors" will be read by Mr. Gus A. Maier, of the Power and Mining Department of the General Electric Company, Schenectady, N. Y.

The Meetings and Papers Committee has felt that there is a demand on the part of a large number of members who come to Institute meetings, for an opportunity to meet each other and to discuss matters of interest. This informal reunion usually takes place in the lobby at the opening of the evening and often detains many members from the reading of the paper, or draws them from the discussion later in the evening especially if the meeting lasts until late.

Feeling that it would contribute to the reading and the discussion of the paper, and would also meet the demand for intercourse among the members and serve to increase the attendance and general interest in Institute affairs, the Meetings and Papers Committee have arranged to start promptly the reading of the paper at 8:15 p.m. and to adjourn at 10 o'clock, at which time the tenth floor will be thrown open and the members will go from the auditorium to meet each other in the Institute rooms. Should any prefer to continue the discussion in the auditorium it will be arranged that they may do so. Light refreshments will be served, and if the innovation is a success it will be continued.

Resume of Business Transacted at Meeting of the Board of Directors of the A.I.E.E. held November 10, 1911

The regular monthly meeting of the Board of Directors of the Institute was held in New York on Friday afternoon, November 10. The following Directors were present: President Gano Dunn, New York, Past-president Dugald C. Jackson, Boston, Vice-presidents H. W. Buck and W. G. Carlton, New York, David B. Rushmore and Charles W. Stone, Schenectady, N. Y., Managers William S. Murray, New Haven, Conn., Henry H. Norris, Ithaca, N. Y., H. H. Barnes, Jr., Charles E. Scribner and Severn D. Sprong, New York, Treasurer George A. Hamilton, Elizabeth, N. J., and Acting Secretary F. L. Hutchinson, New York.

The Finance Committee reported its approval of the monthly bills of the Institute, amounting to $5,939.67, and the action of the committee was ratified.

Upon recommendation of the Meetings and Papers Committee it was voted to hold a smoker in the Institute rooms on the tenth floor of the Engineers' Building, after each monthly meeting, for the purpose of affording facilities for social intercourse among the members in attendance, and an appropriation not to exceed $50.00 per meeting was authorized for this purpose, beginning with the December meeting.

Digitized by Google

The report of the Board of Examiners meeting held on November 6, was read and approved.

Forty-nine candidates for admission to the Institute as Associates were elected, and 163 students were ordered enrolled.

Upon recommendation of the Sections Committee a petition for authority to organize a Branch at the Rose Polytechnic Institute, Terre Haute, Ind., was granted.

The special committee on the proposed Panama trip reported that the number of replies received from the membership to the preliminary circular was sufficient to justify undertaking the trip, and the committee further reported that with the approval of the Board, the date of departure from New York via steamer of the United Fruit Company will be January 18, 1911, arriving in New York on the return trip on February 8; another steamer to leave New Orleans on January 20 arriving in New Orleans on the return trip on February 6. It was

Resolved, that the report of the Committee on the proposed Panama visit be accepted and that the Institute undertake the trip to the Isthmus under the conditions embodied in the report.

The invitation to the Institute of the National Waterways Commission of the U. S. Congress to take part in the hearings set for November 21 on the development of Water-powers, was presented and considered and was referred with instructions to the Public Policy Committee.

The following resolutions were adopted:

Whereas, Mr. Edward D. Adams, to whom the Institute has in the past been indebted for many benefactions, has added to these a bronze bust of the distinguished physicist and mathematician, Hermann von Helmholtz, which in addition to testifying to the public spirit of the donor carries with it associations of the friendly relations existing between the electrical engineers of Germany and those of America, it is

Resolved, that the American Institute of Electrical Engineers hereby expresses its thanks for this gift, and, recognizing the influence of the work of Von Helmholtz upon the practice of electrical engineering in America, expresses its deep appreciation to Mr. Adams for placing among its valued possessions the memorial of the great German leader of scientific thought.

Resolved, that the Board of Directors of the American Institute of Electrical Engineers expresses its appreciation of the courtesy of its sister society, the Verband Deutscher Elektrotechniker, of Berlin, in appointing and sending a representative to be present on the occasion of the presentation of the bust of Von Helmholtz by Mr. Edward D. Adams, which action is most happy because it gives opportunity for the recognition of the influence of Von Helmholtz upon the practice of electrical engineering in the United States.

Upon invitation the President was authorized to appoint a representative upon the United States Committee in connection with the proposed International Congress for the Prevention of Accidents, and Industrial Hygiene, in Milan, Italy, 1912.

Upon recommendation of the special committee appointed to draft resolutions expressing the thanks of the Institute to the various authorities abroad from whom hospitalities were received by the American delegation in Turin, the following resolution was adopted:

Resolved, that the President be requested to make formal acknowledgement of the courtesies extended to the delegation representing the Institute at Turin by sending official letters of thanks signed by him.

An invitation to the Institute to join the Eighth International Congress of Applied Chemistry, to be held in September, 1912, was accepted, and the President was authorized to appoint a representative of the Institute to attend the Congress.

The President announced the appointment of the Standards Committee, as follows:

Messrs. Arthur E. Kennelly, Chairman, Comfort A. Adams, Secretary, Frederick Bedell, William C. L. Eglin, Henry W. Fisher, Benjamin G. Lamme, Wilbur L. Merrill, Harold Pender, William H. Powell, Charles Robbins, Edward B. Rosa, Charles F. Scott, Clayton H. Sharp, Charles P. Steinmetz, J. Franklin Stevens.

Upon recommendation of the Code of Ethics Committee, the President

Digitized by Google

was authorized to appoint an advisory committee to the Code of Ethics Committee, consisting of men prominent in the electrical profession.

A communication was read from Mr. Oberlin Smith suggesting that the Institute have on record the photograph of each member and the details of his career. The Secretary was instructed to express to Mr. Smith the thanks of the Board for his suggestions, and the communication was referred to the Board of Examiners.

Water Power Development

HEARING BEFORE UNITED STATES NATIONAL WATERWAYS COMMISSION, WASHINGTON, D.C., NOV. 21, 1911

The difficult and unsatisfactory situation existing at present in regard to the development of water-powers of the United States, some time ago led the United States National Waterways Commission to set a public hearing for the discussion of water-power questions in Washington on November 21. The American Institute of Electrical Engineers was invited to attend and to contribute to this discussion, as were also a number of other societies and certain individuals prominent in the field of water-power development. The Board of Directors regarded the acceptance of this invitation as a duty to the membership of the Institute in view of the provisions of the Constitution and in view of the public nature of the questions raised. On November 10, after careful consideration, and on recommendation of the Public Policy Committee, it passed the following resolutions unanimously:

Resolved, that the Public Policy Committee be authorized to attend the hearing set for November 21, before the National Waterways Commission, and to express its views on the development of water-powers, keeping these views as far as possible within the limits of engineering questions and presenting them through the means of a written brief and such discussions of this brief at Washington as may be necessary to make the views contained in the brief clear.

Resolved, that the President be authorized to request the co-operation with the Public Policy Committee, of such members of the Institute who are experts on water-power development as the committee feels would help its deliberations and its standing at the hearing at Washington.

The President appointed as the Advisory Members called for in the resolutions Messrs. Edward D. Adams, Philip P. Barton, Louis Bell, Dugald C. Jackson, William S. Lee, Lewis B. Stillwell, and Percy H. Thomas.

The Public Policy Committee appointed a sub-committee consisting of President Dunn and Mr. W. H. Buck, to make a preliminary draft expressing its views, which draft was submitted to a full meeting of the Public Policy Committee and the Advisory Members and was modified to conform to and to represent their joint opinion. On November 20th the President of the Institute, Mr. Stott, Chairman of the Public Policy Committee, and Messrs. Townley, Stillwell and Finney, went to Washington to represent the Institute at the hearing which, on November 21st and the morning of November 22, was devoted by the Commission to the presentation of the Institute's views and such discussion of them as was brought out by questions of the Commissioners.

President Dunn defined the attitude of the American Institute of Electrical Engineers towards the issues by pointing out to the Commission that the Institute was a scientific and professional body and not commercial, that it refrained from making suggestions or expressing its views on the commercial, political, legal, or other aspects of the water-power situation excepting as these were incidental to the questions of electrical engineering involved and which it brought to the attention of the Commission. He also discussed under cross-examination by the Commission the factors determining the rates for water-power, the statistics on developed and undeveloped water-powers in the United States, and the engineering as distinguished from the commercial advantages of interconnection of contiguous hydro-electric systems.

Mr. L. B. Stillwell answered questions of the Commission in regard to dis-

Digitized by Google

tances over which electric transmission was possible, the causes of interruptions to service in hydroelectric systems as compared to the same interruptions in steam-electric systems, and the difficulties in securing capital on account of the large investment required by hydroelectric systems. He also pointed out that the value of a stream as a source of power is usually much greater than its value as a waterway.

Mr. Calvert Townley presented to the Commission most convincing views in regard to the difficulties under which hydroelectric systems labored in their early stages from failure of their expected market to develop, and answered many questions of the Commission regarding the development of water-powers in New England, and the bearing of steam auxiliaries upon the income of hydroelectric systems.

Mr. Stott on the second day of the hearing gave authoritative information on the rate at which the cost of coal had been rising in the last decade and the amount of coal consumed per horse power in steam stations had been falling. He was questioned by the Commission in regard to the control steam competition exercised over the rates of hydroelectric companies, and on the first cost of investment in steam-electric stations.

Mr. Finney described the interconnections of the plants of the Southern Power Company, and the advantages not only engineering but otherwise that resulted therefrom, and gave important information to the Commission upon the opportunities for the utilization of secondary power of hydroelectric systems for electro-chemical purposes. Mr. Finney also answered many questions of the Commission in regard to the general relations of the water-power companies of the south and the statistics on their markets, and other information.

Mr. Edward D. Adams as one of the individuals specially invited by the Commission submitted views to the Commission in writing upon the economic features of the question.

The Institute delegation left after the morning hearing on November 22. The rest of the hearing was devoted to other Societies and to members of the National Electric Light Association.

The brief required by the Board of Directors appears on page 2503 of this issue of the PROCEEDINGS.

Von Helmholtz Bust Presentation

A pleasing feature of the American Institute of Electrical Engineers meeting held in New York, November 10, 1911 was the presentation by Edward D. Adams of a bronze bust of the great German Scientist Hermann von Helmholtz. President Gano Dunn called the meeting to order and spoke as follows:

REMARKS OF PRESIDENT DUNN

Engineers have two sides to them, as this meeting has two parts. A distinguished citizen of the United States, a public spirited resident of the City of New York, a most liberal associate member of the American Institute of Electrical Engineers, has for long given us evidence of his attitude towards the welfare of the Institute. As a first and personal part of our meeting we are very happy this evening to make a public acknowledgment of the indebtedness of the American Institute of Electrical Engineers to Mr. Adams. Those of you who have been identified with electrical engineering for some time know what Mr. Adams has done. For those who are new in the ranks, I would say that Mr. Adams has played the part of engineer-financier in undertakings in which we as electrical engineers have been deeply interested.

I call your attention back to the time when, strange as it may seem, the question of long distance power was a doubtful one, and when transmission of the wonderful power of Niagara Falls was a subject to talk about, but not to act on. The elec-

Digitized by Google

trical engineers contributed their share to the best of their ability at that time, and Mr. Adams, representing the power of finance, secured that other element that is no less necessary to make a successful enterprise. In fact he did more. He passed upon the plans with engineering insight. His possession of, in addition to the degree of Doctor of Laws, that of Master of Sciences is something that many of you do not know and I feel that he deserves the title Engineer-Financier. It is, therefore, with great pleasure that we devote the opening part of this meeting of the Institute to recognizing the last of the benefactions of Mr. Adams, a bronze bust of the great German physicist and mathematician, von Helmholtz, given to the Institute to be placed among its memorials, and I call upon Mr. T. C. Martin, the Chairman of our Historical Committee, to represent us in accepting the gift.

ADDRESS OF MR. T. C. MARTIN

Mr. President, Fellow Members:

I have the honor and the privilege, as your Chairman of the Historical and Museum Committee, of accepting this evening from Mr. Edward D. Adams, our fellow member, this beautiful bust of Hermann von Helmholtz and of transferring it to your custody, Mr. President, as representing the Institute. This is not the only benefaction that the Institute has enjoyed at the hands of its member, Mr. Adams, because if you will visit, as many of you no doubt do frequently, the magnificent engineering library in this building, you will find enshrined there and in frequent use the transactions and proceedings of the two great scientific and philosophical societies of Germany and of England; these volumes were presented to us and are maintained by Mr. Adams.

Those of you who have visited the Metropolitan Museum in this City, will recognize that it is not only science, but literature and art which interests this distinguished citizen of New York, for it has been a pleasure to Mr. Adams to bring to the notice of his fellow countrymen in America, not merely the science of Germany, but the artistic treasures and resources of the fatherland as well.

Professor von Helmholtz held for 40 years the scientific leadership of Europe, and thereby the scientific leadership of the world, and what a wonderful 40 years it was. He who, as a young physician and physicist began the microscopic study of the invertebrates and vibriones gave not long after to the world the ophthalmoscope and after marching from triumph to triumph in the conquest of the material world, rounded out his career as President of the International Electrical Congress, in Chicago in 1893.

It cannot be said that von Helmholtz contributed much directly to our electrical arts, but when we remember that, as regards the great doctrine of the conservation of energy, his was the earliest perception, the strongest grasp, the deepest conviction and the clearest enunciation, we cannot but feel that amongst our immortals he is entitled to a high niche. For von Helmholtz conservation was not a mere political propaganda, but the deepest philosophy.

It was not simply in that connection that he comes near to us. We feel that we know him intimately, and on the basis of personality, through our fellow members who were his pupils and his students, men whom we are proud to number in our membership.

As illustrative of his Teutonic thoroughness and spirit of inquiry, I may be permitted to mention that while he was in Chicago in 1893 he collected from the local electric light company all the forms and blanks which bore upon the system of central station accounting.

With regard to the past itself, I leave to my friend, Dr. Franke, who will represent our German colleagues, more intimate reference to the recognition of

Digitized by Google

von Helmholtz and to his personal qualities.

The following is a copy of a letter sent by Edward D. Adams to Dr. Samuel Sheldon, Chairman, Library Committee, under date of July 13, 1911:

I have been able to obtain a complete set of the publications of the Physikalisch-Technische Reichsanstalt, of Charlottenburg, Berlin, which its President, Herr Ministerial-direktor Dr. Lewald, has kindly forwarded, and I now take pleasure on his behalf in presenting the same to the American Institute of Electrical Engineers.

The case containing these publications should be delivered at the above address free of all charges. You will find a list of the documents on the top of the books.

Professor Dr. H. von Helmholtz was the first President of the Institute. The courtesy thus extended to your Institute has been inspired by the influence of Mr. Arnold von Siemens, Chairman of Siemens & Halske, who is a son of Dr. Werner von Siemens and son-in-law of Dr. H. von Helmholtz.

In this connection I am prompted to refer to the bronze bust of Helmholtz by the sculptor von Hildebrand, and to state, as of possible interest in this connection, that the original of this bust was executed in marble, and is now in the possession of his daughter, Mrs. Arnold von Siemens, and upon her death it is intended to go to one of the museums or institutes of Berlin. A replica in marble was also made, that is owned by Mr. Arnold von Siemens, and is a pendant to the marble bust, also by von Hildebrand, of Dr. Werner von Siemens, in the country home of Mr. Arnold von Siemens. I understand from the family that no other reproductions have been made than that made expressly for the American Institute of Electrical Engineers.

We are highly favored in having such a beautiful and unique work of art. The American Institute of Electrical Engineers has at the present moment very few relics, mementoes, works of art and memorabilia of this character, and as Chairman of its Historical Committee, I would like to avail myself, Mr. President and Fellow Members, of the opportunity to urge upon you the value and importance of the work which is entrusted to the hands of that Committee. We have at this moment but three busts and therefore I avail myself of the occasion to suggest to you that in this palpitating moment of the present we do what we can to emulate the generous example of our munificent fellow member and help to hand down to posterity in documents, in models, in relics, in vivid canvass and in animated busts, the records of these times and days which have done so much to produce great inventions and great men in the domain of electricity.

President Dunn: If Mr. Adams had given merely the bust of a great man like von Helmholtz, it would have been a gracious gift, but there has been behind this gift something of greater significance. You all know the intimate relations Mr. Adams has with German affairs and with Germans. A desire to increase the friendly relations between electrical engineers in America and electrical engineers in Germany has shared in inspiring Mr. Adams' gift. Appreciating this fact, the Verband Deutscher Elektrotechniker, our sister Society of Germany, on learning of this occasion from the representatives of the Institute at the International Electrical Congress at Turin, have done us the honor of sending a representative to attend this presentation and to respond on their behalf.

We have with us Dr. Adolf Franke, of Berlin, who has been sent by the Verband Deutscher Elektrotechniker, our sister Society, to greet us tonight and to express their feelings in regard to German-American relations in electrical engineering, and it was with particular appropriateness of feeling that they chose to represent them a man who in his university days had felt the stamp of the genius of von Helmholtz, who was von Helmholtz's pupil in every way that a man can be, who felt the influence of von Helmholtz's intellect, and the influence of von Helmholtz's personality. It is, therefore, with particular pleasure that I now call upon Dr. Franke to respond.

Address of Dr. Franke

Mr. President and Gentlemen:

Just before my departure from Germany several weeks ago I received a communication from the Secretary of the Verband Deutscher Elektro-

Digitized by Google

techniker, Mr. Dettmar, notifying me that the American Institute of Electrical Engineers had accepted a Helmholtz bust presented to them by Mr. E. D. Adams, and intended to call a formal meeting with the object of receiving this generous gift. Mr. Dettmar requested me to be present at this meeting as the representative of the Verband Deutscher Elektrotechniker. I have been able to accept this honored commission, and now take pleasure in extending the heartiest greetings from the members of the Society I represent which, as you know, is furthering the same branch of science as your honored body — especially on this day on which you again pay tribute to one of the foremost men, surely the foremost physicist that Germany has produced, whose prominence also was recognized in this country during this life.

The fact that it is the American electrical engineers who, above all others, have dealt with the large problems of industry within the last decades, who are so honoring this man, shows that they have not forgotten the fact that in the end pure science is the foundation of their success.

It is not my purpose to recite to you the deeds and accomplishments of Helmholtz, as they are surely as much studied and as well known in this country as to us in Europe. Today's celebration offers me the opportunity to recall past days when I, with hundreds of others, among whom were several sons of the United States, was fortunate enough to have the opportunity of drawing directly from this pure source of science. I believe I can safely say that all of us not only have never forgotten the vivid impressions received from this great scientist, but have also felt the mighty influence of this man upon their character and personality. His thoughts were so deep, his genius moved in such lofty heights, that it was sometimes difficult for younger students to follow, but those who had already a deeper insight into science received invaluable inspirations from his teachings. Above all, it was his intuitive power to see the common principles in the different physical phenomena, and further his thoroughness with which he differentiated between theories of speculative character and laws and facts which we are permitted to consider as proven, due to the fact that they again and again have been verified by experiments, which stands in the eyes of every one of his pupils as a high ideal in life for which to strike and follow.

The bronze bust of Helmholtz now in your possession is the work of Adolph Hildebrandt, the well known sculptor, for whom Helmholtz himself posed for several sittings in the year 1891, at which time a marble bust was completed for his seventieth birthday. It may be of interest here to mention a letter which the wife of Helmholtz wrote to her daughter two years later, shortly before his trip to America, in which she spoke of the evident aging of her husband. She wrote:

> Day by day he resembles more and more his bust as if Hildebrandt had foreseen his future appearance in expression and carriage.

The cost of the bust of Helmholtz which is now in the possession of his daughter, Mrs. Ellen von Siemens, was covered by a collection taken up by his friends and pupils from all corners of the world. This collection exceeded the necessary amount so that enough was left for an etching of his head to be made by Jacoby, and a medallion by Teutenhym. Such a medallion is awarded from time to time to prominent scientists.

In all events, this bust now in your possession is a work of great value from an artistic point of view.

In fulfillment of my mission, I now convey to you the heartiest greetings and good wishes of the Verband Deutscher Elektrotechniker and its members, and express the hope that the two Institutes and their members will further succeed in developing in a peaceful and friendly competition for the

Digitized by Google

benefit of mankind that field which they have in common.

President Dunn: There is no testimony so fine to the memory of a man as that from an old pupil. The words that Dr. Franke has told us of von Helmholtz are impressed with memories of the days of old.

It seems only fitting, and as expressly demonstrating the fact of von Helmholtz's influence in America, that on this occasion there should also be given an opportunity to be heard, one whom we may call an American pupil of von Helmholtz, who was sent out from under that great influence in Germany to do his work here, one who has made a brilliant record, to whom the possession of genius will be accorded by all. It is with pleasure that I now ask Mr. B. A. Behrend to say a few words in appreciation of von Helmholtz from an American point of view.

ADDRESS OF MR. B. A. BEHREND

Mr. President, Dr. Franke, Members and Guests:

It is with great satisfaction that I respond to the invitation of President Dunn to say a few words on this occasion. I have sat at the feet of Helmholtz, I have gained inspiration from his lips and from his personality. This bronze bust is an excellent likeness of the great master whom the sculptor has endeavored to portray. Hermann Helmholtz does not belong to any one narrow branch of science. His genius enlightened with new creative thoughts the entire field of human knowledge. In medicine and in physiology, in mathematics and in physical science, in philosophy and metaphysics, in each and in all his genius was a beacon fire like that of Newton and of Darwin. We unite with the name of Newton our knowledge of the laws of motion; with the name of Darwin our knowledge of the law of evolution and of natural selection; with the name of Helmholtz, our knowledge of the law of conservation of energy. Loftiest and broadest of human minds, there stands the monumental intellectual figure of Helmholtz forever in the annals of science. There is no need to inscribe " His Excellency " upon his tomb; the name he bore runs no more risk of oblivion than that of Galileo or that of Newton. Nor do we honor the master by this memorial, we are pleased to accept this monument from the hands of one who, himself, has been a great furtherer of the art of electrical engineering for the advance of which this Institute was founded. The bust of Helmholtz will show future generations who pass this entrance hall, the man whose example they must follow, if they wish to uphold the standard of science where he placed it. And to me, who have known the master, and who am the generous donor's friend, it is a pleasant privilege to say these words on this occasion.

President Dunn: We have received the following letter:

German Embassy, Washington, D. C.,
Nov. 7, 1911.

DEAR SIR:

I have learned with great pleasure of Mr. Edward D. Adams' generous intention to present a Helmholtz bust to the American Institute of Electrical Engineers on November 10th. I beg you to kindly present my compliments to Institution and donor and to express to them my most sincere congratulations on this occasion, which you will permit me to consider not only as a mark of respect to the memory of the celebrated scientist, but as another link in the ties of friendship and mutual understanding which unite our two countries.

Believe me, dear sir,

Yours respectfully,

HANIEL VON HAIMHAUSEN,
German Charge d'Affaires.

President Dunn,
American Institute of Electrical Engineers,
New York.

We also have received a telephone message from His Excellency, the German Consul General of the City of New York, regretting that official engagements prevent his presence, and we also have a cable from the Verband Deutscher Elektrotechniker which reads as follows,

Digitized by Google

" To their Colleagues of the American Institute of Electrical Engineers the Verband Deutscher Elektrotechniker sends heartiest greetings.

[Signed]

BUDDE DETTMAR ".

And now, gentlemen, when I have read this resolution passed by the Board of Directors this afternoon, I shall ask as many as concur in it, and desire to emphasize it to do so by saying " aye " with a good loud voice.

Resolved, That the Board of Directors of the American Institute of Electrical Engineers expresses its appreciation for the courtesy of their sister Society, the Verband Deutscher Elektrotechniker in appointing and sending a representative to be present on the occasion of the presentation of the bust of von Helmholtz by Mr. Edward D. Adams, which action is most happy because it gives opportunity for the recognition of the influence of von Helmholtz upon the practice of electrical engineering in the United States.

The resolution was applauded with enthusiasm.

President Dunn: I have great pleasure in calling Dr. Franke's attention to this communication, and telling him that it is our intention to send the following cable to his Society at Berlin, in addition to transmitting it by him.

American Institute of Electrical Engineers in meeting assembled returns heartiest greetings to Verband Deutscher Elektrotechniker, on happy occasion of visit of delegate.

GANO DUNN,

President.

Another resolution passed by the Board of Directors was as follows:

Whereas, Mr. Edward D. Adams, to whom the Institute has in the past been indebted for many benefactions, has added to these a bronze bust of the distinguished physicist and mathematician, Hermann von Helmholtz, which in addition to testifying to the public spirit of the donor carries with it associations of the friendly relations existing between the electrical engineers of Germany and those of America, it is,

Resolved, That the American Institute of Electrical Engineers hereby expresses its thanks for this gift, and, recognizing the influence of the work of von Helmholtz upon the practice of electrical engineering in America, expresses its deep appreciation to Mr. Adams for placing among its valued possessions the memorial of the great German leader of scientific thought.

This resolution of the Board of Directors was heartily approved by those present at the meeting.

President Dunn: Mr. Adams, it gives me much pleasure, to call this resolution of the Board and its hearty approval by this meeting to your attention.

And now gentlemen, Mr. Adams tonight particularly asked not to be called on to speak, and I am not going to call on him. If I have dubbed him the Engineer-Financier, I know it is a title which you will all accord him, and if he should be willing in mere acceptance of his title to give us a few words on any subject, even Niagara Falls, I am sure we should be very much pleased to hear anything he might have to say.

RESPONSE OF MR. EDWARD D. ADAMS

Mr. Chairman and Gentlemen:

He indeed would be lacking in courtesy who would not respond to such a cordial invitation as that which you have given me. And I am embarrassed by the constant allusions to simply the impulses that expressed sympathy with what you are living for in your professional life. I am deeply grateful, I assure you, Mr. President and Gentlemen of the Institute, for this manifestation of my success in pleasing you, because you undoubtedly believe me that it was done for that purpose, as well as for the idea that I had of bringing science in this country in the measure that it might be able to follow the progress of art, which I have no doubt you have all recognized, has been from the East to the West. It has differed from the progress of music, which those of you who have followed its history, will recognize has been from the Equator to the Northern countries. Science has progressed in its measure of activities westward on the continent, across England, and I think we may pride ourselves today that it has found not only a lodging upon this continent, but here, with the activities of invention, with the novelty of research, with the audacity that is characteristic of our people, there is a future for science which we may hope has

Digitized by Google

never been equalled in any other countries of the older nations.

Were I to refer to a somewhat varied and long experience in the application not only of electrical, but other sciences, to the industrial arts, I would indeed take much of your time, but as the subject of that great event in the application and development of electricity Niagara Falls, has been referred to, I am reminded of some of the lessons that came to me in studying the problem, in the solution of which Niagara Falls stands today as an example. And I speak of this, because I have tried in some of my contributions to this Institute to teach the lesson that I learned in the problem that we had before us there in 1889–1890.

Many of you no doubt will recall the fact that Edison's Jumbo at that time was a magnificent and powerful instrument for the creation of electrical current. I remember, in making my inquiries as to what represented the highest state of the art, that was held up to me as the most illustrious example of progress in electrical science. Remembering those days, and the appliances which we had at that time, it seems miraculous that in so short a time our ideas would have been so greatly changed, and the progress so marvelous. I also recall that at that time the alternating current was then under consideration as to whether death by it was torture or a happy passing into oblivion.

Mr. Edison at my request gladly undertook, as he expressed it, the examination of the City of Buffalo for the use of power. He made a house to house canvass, and informed us that we were justified generally in expecting to use at least 50,000 h.p. in that municipality and its vicinity, at a cost of transmission and distribution of at least $10,000,000, and he so valued the chart of users and distribution that he had made, that he declined my proposition to reimburse him for his expenses in making the investigation, as he considered the record so valuable that he preferred to retain it for his own private property.

I very soon found that the state of art was not represented in published works, but that the advance front of the invention and application of electricity at that time was to be found only in what you might call current literature, that is to say, in the accounts of papers presented before the scientific societies, and communications made to the press of different nations, representing what had been done in the laboratory and had not yet reached, possibly, a recognition by the public as to its practical use. So that one of our first undertakings was to keep posted, so that whatever we installed at Niagara Falls might represent at the period of installation the most advanced state of the electric art, as applied to industrial purposes, not only that it represent the advanced state of the art at that moment, but, although it might not be recognized by all, we, at least, desired the endorsement of the leading scientists of the day, hence the inauguration of what you have all heard of under the title of "The Niagara Commission" that had its first sitting in London, and on which there was an international representation of the scientists of four different countries.

To show what was being done, we had clippings made from all the technical journals published in America, in England, in France, in Italy, in Switzerland, and in Germany, and I remember the satisfaction that I experienced when we gave the award of the first dynamo, in looking up these great books full of these clippings, and feeling that what we were then doing was in accord with the latest information that had come by mail only a few days before the award was given, and this information came from an Italian paper. That represented the latest discoveries of the electricians in Italy. At no time since we made our decision, have we regretted that we did what we did, according to the best knowledge

Digitized by Google

obtainable at that time. No one has ever asked—If you had known of such a thing at that time, would you have done differently? That taught me the advantage of having the earliest information obtainable from such sources, which, I think you can all understand, are available sometimes a year, and sometimes several years before they appear in the technical books which we place on our library shelves. For that reason in the endowment of a Chair at Columbia College for Physical Research, it was provided in the deed of trust that it should publish and circulate promptly the results of the research made by the scientists from different parts of the world, and thereby secure from that fund what is intended to be accomplished. In the same way, this grand technical institution at Charlottenburg has furnished us with the evidence of the work that goes on there, and you will find a complete record of the past in the library of the Institute; and I am sure from time to time, as the physicists remember how the results of their research work thus will come here to our files, and we may thus know, before they become of general public knowledge through the publication of technical papers as well as books, what they have accomplished and what will help the latest developments of the physical research in these great laboratories in our country, we shall have a larger cooperation in the exchange of this information.

There is another feature of that experience which I would allude to, and that is in industrial work the manager or the guiding spirit is much embarrassed nowadays in the employment of experts. It seems as though there had been a very great change since Lord Kelvin announced that an electrical engineer was about nine-tenths mechanical and one-tenth electrical. It was only a few years when that statement was modified by the introduction of the chemical engineer, and how far the subdivision may be made at the present time I am at a loss to say, and fancy some of you may be, when you realize that those who attempt to estimate the number of subdivisions of engineering today have reached more than one hundred, thus indicating the specialization into which engineering work is now being subdivided. In many industrial applications for a single purpose it is often the case that four experts in their several specialties must necessarily be consulted. While we have this subdivision in practical work, we can certainly see the disadvantage that would result if we attempted to subdivide our interests. Instead of there being a subdivision, it seems to me there should be a consolidation, at least, in the sense that this Institute, while it has its various departments, representing the specialties of its membership, yet its members should seek the strength that comes from the aggregation of all these interests, and if, perchance, I may contribute to it, I hope you will get some of the advantages of my experience.

After the close of the presentation ceremonies the reading of the technical paper of the evening was taken up.

A. I. E. E. Meeting in New York, November 10, 1911

The two hundred and sixty-fifth meeting of the American Institute of Electrical Engineers was held in the Engineers' Building, 33 West 39th Street, New York City, on Friday, November 10, 1911. The earlier part of the evening was taken up by the Von Helmholtz bust presentation ceremonies, an extended report of which will be found elsewhere in this issue. At the conclusion of these ceremonies a paper entitled "Magnetic Properties of Iron at Frequencies up to 200,000 Cycles" was presented by Mr. E. F. Alexanderson, of the General Electric Company. The paper was discussed by Dr. Harold Pender, Mr. B. A. Behrend, and Dr. C. P. Steinmetz.

Digitized by Google

Panama Trip

The committee on Panama trip is pleased to announce that the response of the membership to its circular of October 28th has been so favorable that the Board of Directors at its meeting of November 10th approved the recommendation of the committee that the trip be undertaken.

The general scope of the trip as finally arranged for is in accordance with the circular of October 28th. The details of itinerary, etc., are as follows:

ITINERARY OF THE NEW YORK PARTY

Leave New York	Wednesday,	Jan. 17	12 noon
Arrive Port Antonio	Monday,	" 22	6 A.M.
Leave Port Antonio	"	" 22	8 A.M.
Arrive Kingston	"	" 22	2 P.M.
Leave Kingston	Tuesday,	" 23	6 P.M.
Arrive Colon	Thursday,	" 25	12 noon
Leave Colon	Friday,	" 26	5 P.M.
Arrive Santa Marta	Sunday,	" 28	6 A.M.
Leave Santa Marta	Tuesday,	" 30	5 P.M.
Arrive Colon	Thursday,	Feb. 1	7 A.M.
Leave Colon	"	" 1	11 A.M.
For New York via Kingston and Port Antonio.			
Arrive New York	Thursday,	Feb. 8	2 P.M.

Upon arrival at Port Antonio, Jamaica, the party may disembark and take breakfast at the splendid Hotel Titchfield, thence *via* special train to Kingston and rejoin the ship. The additional charge of this side trip and breakfast will be about $6 per capita.

Rates per person from New York and return, including meals and stateroom berth (but without accommodations at Panama):

In stateroom without bath	$125 00
" " with bath	163 00
" suite	210 50

ITINERARY OF NEW ORLEANS PARTY

Leave New Orleans	Saturday,	Jan. 20	11 A.M.
Arrive Colon	Thursday,	" 25	7 A.M.
Leave Colon	Monday,	" 29	5 P.M.
Arrive Bocas del Toro	Tuesday	" 30	6 A.M.
Leave Bocas del Toro	Wednesday	" 31	6 P.M.
Arrive Colon	Thursday,	Feb. 1	6 A.M.
Leave Colon	"	" 1	3 P.M.
Arrive New Orleans	Tuesday,	" 6	6 A.M.

The rates per person for this trip will be:

In stateroom	$95 00
In suite	142 50

It should be noted particularly that there are no second-cabin accommodations on these vessels; all the rooms are desirable. There are but five rooms with bath and two suites on the vessel sailing from New York. The steamer from New Orleans has similar accommodations with the exception of private baths and they will be assigned in the order of receipt of applications for them. It should be noted that the suites accommodate two or three and can therefore be assigned only to members of one party of this number.

Upon arrival at Colon the party may take accommodations at the Hotel Tivoli, Panama City. The committee will arrange for the reservation of accommodations at the Tivoli for the total number in the party, sailing from New York and New Orleans.

The United Fruit Company advise that, although they assign but two to a room, many of their rooms are large enough to accommodate three people by the use of a convertible couch, so that a family of three or three friends traveling together could find one of these rooms sufficient for their needs. Therefore the committee suggest that wherever possible parties of three be formed in accordance with the above in order to increase the capacity of the ship. This applies especially to the New York party, as applications exceeding the capacity of the ship—88—will probably be received.

As the stopover of one week at Panama enables the excursionists to return on the same steamer, interesting extension trips are available for those of the party who do not care to remain at Panama. The New York steamer on the down trip remains one and one-half days at Colon and then proceeds to the port of Santa Marta for the purpose of taking on cargo for New York or New Orleans. The round trip from Panama to Santa Marta takes about five days. Those who care to extend their trip in this way can do so without extra charge. Similarly the members of the New Orleans party may make the extension trip as shown

Digitized by Google

in the itinerary to Bocas del Toro without extra charge.

Regarding the expressed desire of the committee to limit the party to adults, this applies to the New York party for reasons already given, except when a child is the third member of the party, and the family will require but one room under the conditions as noted above for the accommodation of three in a room. This restriction, however, does not apply to the New Orleans party, as there will probably be ample accommodation for all who wish to go from New Orleans. The rates which apply to children from both New York and New Orleans are as follows: Three to eight years, one-quarter fare; eight to twelve years, half fare; over twelve, full fare.

As stated in the circular, mailed November 18 to all members whose replies indicated they would probably participate, our agreement with the United Fruit Company is that they will hold for our disposal the total accommodations (88 on a two in a room basis) of the ship sailing from New York January 17th and that from New Orleans January 20th until December 1st, at which time we are to advise them of the number and class of accommodations required and for such accommodations as are assigned a fifty per cent payment is to be made to the United Fruit Company. It will therefore be evident to other members who desire to join the party that they should forward their applications to Institute headquarters immediately, accompanied by the necessary remittance as explained below.

Available accommodations will be assigned in the order of the postmark dates of applications.

It should be noted that the replies received by the committee to the circular of October 28th cannot be considered as reservations. The sole purpose of that circular was to determine whether enough would probably go to justify arranging for the trip.

Applications should state number in party, names, accommodations preferred, whether it is desired to sail from New York or New Orleans, and must, in order to secure reservation be accompanied by fifty per cent of cost of accommodations desired. Remittances should be made payable to Mr. F. L. Hutchinson, Acting Secretary, A. I. E. E.

While some may wish to go from one port and return to another, the committee cannot make arrangements of this kind. However, if the individual can find another who wishes to travel in the reverse order, arrangements may be made between the parties concerned and an adjustment of rates made with the United Fruit Company. It should be noted by those who will travel alone that at least two will be assigned to a stateroom. In case accommodations requested cannot be assigned, any excess of remittance to cover the requested accommodations as compared with those assigned will be returned, or credited on final payment, as directed.

In all arrangements made by the committee as between the individual and the United Fruit Company the committee acts only as the agent of the individual.

It should be noted particularly that this trip will have the nature of a mid-winter convention, as a number of papers will be presented and discussed. This matter is in the hands of the Meetings and Papers Committee.

COMMITTEE ON PANAMA TRIP,
S. D. SPRONG, *Chairman.*
Nov. 24, 1911.

Future Section Meetings

The December meeting of the Washington Section will be held in the Telephone Building, Washington, D. C., on Tuesday evening, December 12. An out-of-town speaker will deliver an address the subject of which will be announced later.

Digitized by Google

Associates Elected November 10, 1911

ANDERSON, ERNEST R., Motor Engineer, General Electric Co.; res., 88 Lyman St., Pittsfield, Mass.

ASHLEY, EDWARD EVERETT, JR., Mechanical Engineer, 527 Fifth Ave.; res., 717 West 177th St., New York City.

BELL, JOHN HUME, Electrical Engineer, Western Electric Co., 463 West St., New York City.

BENSON, MELVIN BERNARD, President, Universal Flash-Light Signal Co.; res., 2405 West 3rd St., Duluth, Minn.

BISBEE, DE WITT WILLIAMS, Chief Electrician, Moctezuma Copper Co., Nacozari, Sonora, Mex.

BOYDEN, DAVIS STUART, Assistant Superintendent, Elec. Engg. Dept., Edison Electric Ill. Co., 39 Boylston St., Boston, Mass.

BURDETTE, HAROLD EUGENE, Secretary Sprinklered Risk Committee, Southeastern Underwriters Ass'n., 542 Equitable Bldg., Atlanta, Ga.

BYERTS, WILLIAM EDWARD, Sales Agent General Electric Co., Chicago, Ill.; res., 104 Oneida Ave., Davenport, Iowa.

CASE, ARTHUR E., Chief Engineer, Baird Electric Co., 3145 N. Halsted St.; res., 805 Bradley Pl., Chicago, Ill.

CLARK, ALFRED TENNYSON, Superintendent of Rolling Stock & Shops, United Railways & Electric Co., Baltimore, Md.

ENNIS, WILLIAM H., Supervising Electrical Engineer, 726 Maison Blanche Bldg.; res., 817 Iberville St., New Orleans, La.

EVANS, GORDON MAYNARD, Engineer, Fuel Engineering Co., 59 Pearl St.; res., 418 West 160th St., New York City.

FREEMAN, WILLIAM EDWIN, Professor of Electrical Engineering, State University of Kentucky, Lexington, Ky.

HAHN, WILLIAM, Electrician, Niagara Gypsum Co., Oakfield, N. Y.

HALL, WILL ALBERT, Assistant Rate Clerk, City Lighting Dept.; res., 203 North 60th St., Seattle, Wash.

HANSELL, CHARLES EARL, Electrical Engineer, Duncan Electrical Mfg. Co.; res., 400 Dodge St., W. La Fayette, Ind.

HARDEY, JOHN ERNEST, Manager and Engineer, National Electrical & Engineering Co., Ltd., Auckland, N. Z.

HAUSER, JOHN EDWARD, Exhibit Engineer, Publicity Dept., National Carbon Co., Cleveland, Ohio.

HAYNES, AMORY ROBINSON, Electrician, Pacific Coast Power Co., White River Station, Dieringer, Wash.

HOWARD, FRANK PARKINSON, Wireman and Electrician, Consolidated Gas, Elec. Lt. & Pr. Co., Baltimore, Md.

JOHANSSON, KARL WILHELM, Draftsman, Westinghouse Electric & Mfg. Co.; res., 6135 Jackson St., Pittsburg, Pa.

KING, EDWIN TERRY, Engineer in charge of inspection, National Carbon Co., Cleveland, Ohio.

KING, JOE EVANS, Industrial & Power Dept., Westinghouse Electric & Mfg. Co., East Pittsburg, Pa.

KORNFELD, FREDERICK H., Engineering Apprentice, General Electric Co.; res., 525 Summit Ave., Schenectady, N. Y.

LESSIG, J. FRANK, Electrical Draughtsman, Lehigh Wilkes-Barre Coal Co., Wilkes-Barre, Pa.

LOFVENGREN, NILS WILLIAM, Engineer, Ferranti, Ltd., 1688 Dundas St.; res., 35 Lappin Ave., Toronto, Ont.

MCKEEN, WILLIAM J., Foreman Inside Construction, Light Dept.; res., 1128 33rd Ave., So., Seattle, Wash.

MEREEN, JOHN DUNNING, Engineer in charge of experimental work, C. A. Smith Lumber & Mfg. Co., Marshfield, Ore.

MILLS, JOHN, Engineering Department, American Telephone & Telegraph Co., 15 Dey St., New YorkCity.

MILTENBERGER, ALEXANDER LASSEN, Sales Department, Wagner Electric Mfg. Co.; res., 3758 W. Pine Blvd., St. Louis, Mo.

MILTON, RICHARD HOLMES, Inspector, City of Greensboro, N. C.

Digitized by Google

MOTOMURA, SEIZO, Electrical Engineer, Machinery Dept., Mitsui & Co., Ltd., Tokyo, Japan.

PAWLETT, LOUIS M., Executive Engineer, Locomobile Company of America; res., 231 Fairfield Ave., Bridgeport, Conn.

PEARCE, SYDNEY HERBERT, Operator, Western Canada Power Co., Ruskin, B. C.

RICHARDSON, GEORGE WILLIAM, Power House Superintendent, Kashmir State Electrical Department, Mohora, Kashmir State, India.

SAEGER, RAYMOND ARTHUR, Electrical Engineering Student, Ankona, Fla.

SCHULZ, ALBERT CHARLES, Assistant Engineer, Locomobile Company of America; res., 337 John St. Bridgeport, Conn.

SCHUTT, CLIFTON ERVIN, Instructor in Electrical Engineering, Purdue University; res., 217 Sylvia St., West Lafayette, Ind.

SILLS, GEORGE FRANCIS, Assistant Electrical Engineer, Siemens Bros. Dynamo Works, Ltd., Canadian Birkbeck Bldg., Toronto, Ont.

SILVIA, GEORGE F., Foreman Construction Department, General Electric Co., Schenectady; res., 122 S. Swan St., Albany, N. Y.

SIMPSON, TRACY WHITTELSEY, Production Engineer, International Harvester Co.; res., 7805 S. Peoria St., Chicago, Ill.

SMITH, EDWARD LEE, Assistant Superintendent, Louisiana Light, Power & Traction Co., Louisiana, Mo.

SMITH, THEODORE CASTLE, Electrical Machinist, City Lighting Department; res., 635 East 70th St., Seattle, Wash.

STOCKBRIDGE, WILLARD ASHLEY, Special Apprentice, Pennsylvania Company; res., 2323 Webster St., Fort Wayne, Ind.

WALTON, ROGER P., Testing Department, General Electric Co.; res., 849 Union St., Schenectady, N. Y.

WEBER, EDWARD, Electrical Switchboard Engineer, General Electric Co.; res., 8 Grove Place, Schenectady, N. Y.

WEBSTER, GLENN C., Manager Engineering Department, National Electric Lamp Ass'n., res., 1849 Crawford Rd., Cleveland, Ohio.

WRIGHT, JAY L., Sales Agent, General Electric Co., 609 Colman Bldg.; res., Hotel Seward, Seattle, Wash.

YAPP, LEON CLARENCE, Electrical En-Engineer, Construction Dept., Ft. Wayne Electric Works; res., 1150 Packard Ave., Ft. Wayne, Ind.

Total, 49.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Acting Secretary before December 26, 1911.

10795 Auty, K. A., Vancouver, B. C.
10796 Bardell, P. H., Chicago, Ill.
10797 Brodie, J. M., West Lynn, Mass.
10798 Cloke, P., Kingston, R. I.
10799 Collins, A. L., San Francisco, Cal.
10800 Estill, D. C., Schenectady, N. Y.
10801 Finsen, E., Niagara Falls, Ont.
10802 Grier, B. R., Gatun, C. Z.
10803 Lennox, J. S., Pittsfield, Mass.
10804 Peters, J. W., New York City.
10805 Walker, A. S., Lynn, Mass.
10806 West, J. W., West Lynn, Mass.
10807 Baruch, M., Los Angeles, Cal.
10808 Buchanan, E. V., London, Eng.
10809 Hutchins, F. A., Swampscott, Mass.
10810 Robinson, L., White Plains, N. Y.
10811 Tyler, H. G., Brooklyn, N. Y.
10812 Wolf, M. A., Newark, N. J.
10813 Bauer, W. C., Evanston, Ill.
10814 Merchant, C. J., Waverly, N. Y.
10815 Barnum, W., Louisville, Ky.
10816 Harrison, W., Jr., Vancouver, B.C.
10817 Moffitt, H. A., Boston, Mass.
10818 Murphy, F. T., Baltimore, Md.

Digitized by Google

10819 Taylor, W. B., Schenectady, N.Y.
10820 Wilson, J. H., Middletown, O.
10821 Crawford, J. M., Winslow, Ariz.
10822 Kneeland, R. P., Lynn, Mass.
10823 McCulloch, R. L., Matsqui, B. C.
10824 McGovern, M.T., Pittsfield, Mass.
10825 Shanks, D. A., Montreal, Que.
10826 Brown, C. E., Orange, N. J.
10827 Brinton, H.G., Schenectady, N.Y.
10828 Forst, A., New York, N. Y.
10829 Gary, L. A., Los Angeles, Cal.
10830 Lawrence, E. F., Berlin, Ger.
10831 Lehmann, E. W., College Sta. Tex.
10832 Spalding, H. K., New York, N.Y.
10833 van Gravesande, J. W. S., Shelburne Falls, Mass.
10834 Willis, S., Lancashire, Eng.
10835 Zebley, J. S., Washington, D. C.
10836 Beatty, J. H., Toronto, Ont.
10837 Beckjord, W. C., St. Paul, Minn.
10838 Bradley, J. C., Waterbury, Conn.
10839 De, B. K., Allahabad, India.
10840 Drew, J. L., Philadelphia, Pa.
10841 Forbes, A. W., East Orange, N. J.
10842 Knowlton, H. S., Newton, Mass.
10843 Loubet, L. M., Schenectady, N.Y.
10844 Roesen, O. C., Brooklyn, N. Y.
10845 Smalley, D. F., Lynn, Mass.
10846 Smerling, D., Swampscott, Mass.
10847 Smith, E. W., Lynn, Mass.
10848 Stevenson, G.H., New York, N.Y.
10849 Strunk, W. C., New York, N. Y.
10850 Valk, E. E., Schenectady, N. Y.
10851 Wexler, L. I., Schenectady, N. Y.
10852 Westcott, B.N., Schenectady, N.Y.
10853 Brown, N. H., Austin, Texas.
10854 Crane, G. S., Milwaukee, Wis.
10855 Dawson, B., Cedar Rapids, Ia.
10856 Duddell, W., London, S. W. Eng.
10857 Edison, C. G., Annapolis, Md.
10858 Jordan, F. J., Vancouver, B. C.
10859 Kapoor, B., Dighoi, India.
10860 Langley, P. G., Schenectady, N.Y
10861 Leitch, G. A., Buenos Aires, A. R.
10862 McCollum, A. B., San Juan, P. R.
10863 Miller, G. S., Buffalo, N. Y.
10864 Robinson, E., Sydney, N. S. W.
10865 Walter, I. H., Maisonneuve, Que.
10866 Woodrow, H. R., New York, N.Y.
10867 Dryer, W. P., Vancouver, B. C.
10868 Lehuraux, L., Schenectady, N. Y.
10869 Nivling, H., New York, N. Y.
10870 Rice, L. N., Spokane, Wash.
10871 Rose, C. E., Little Rock, Ark.
10872 Fellenberg, W. G. O. A., Berlin-Charlottenburg, Germany.
10873 Gentis, R. A., Oakland, Cal.
10874 Harrelson, A. M., St. Louis, Mo.
10875 Israel, L. W., Philadelphia, Pa.
10876 Leahey, E. F., Lone Pine, Cal.
10877 Lindsay, S. C., Seattle, Wash.
10878 Miess, F., Cincinnati, Ohio.
10879 Myers, F. D., Ft. Wayne, Ind.
10880 Shand, J. A., Vancouver, B. C.
10881 Skirm, G. L., Montreal, Que.
10882 Speyer, H. R., Calcutta, Ind.
10883 Stewart, E. D., Dallas, Texas.

Total, 89.

Recommended for Transfer

FREDERICK K. VREELAND, Experimental, Research and Consulting Expert Work, Electrical Testing Laboratories 80th Street and East End Avenue, New York City.

The above named Associate was recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on November 6, 1911. Any objection to the transfer of this Associate should be filed at once with the Acting Secretary.

Students Enrolled November 10, 1911

4563 Argabrite, J. J., Stanford Univ.
4564 Endres, H., Stanford University.
4565 Argabrite, C. C., Stanford Univ.
4566 Marx, R. G, Stanford University.
4567 Waggener, J. F., Colo. Agr. Coll.
4568 McClain, O. E., Univ. of Missouri.
4569 Buergey, I. J., Univ. of Missouri.
4570 Beckman, F. G., Okla. Agr. & Mech. College.
4571 Jenkins, F. O., Univ. of Missouri.
4572 O'Bannon, D. A., Univ. of Mo.
4573 Robinson, E. C., Univ. of Mo.
4574 Hancock, H. D., Univ. of Mo.
4575 Randall, G. B., Univ. of Missouri.
4576 Farthing, J. W., Univ. of Missouri.
4577 Kennard, R., Univ. of Missouri.
4578 Whipple, C. A., Univ. of Missouri.
4579 Bardo, B. F., Cornell University.
4580 Brown, G. E., Univ. of Michigan.
4581 Davidson, W. A., Univ. of Mich.
4582 Taylor, G. A., Univ. of Mich.

Digitized by Google

4583 Hutchinson, F. P., Univ. of Wisc.
4584 Campion, H. H., Univ. of Kansas.
4585 Belt, T. A. E., Univ. of Kansas.
4586 Hartman, E. E., Univ. of Kansas.
4587 Bray, E. L., Univ. of Kansas.
4588 Schooley, S. S., Univ. of Kansas.
4589 Thompson, W. D., Univ. of Kan.
4590 Willmore, H. E., Univ. of Wisc.
4591 Newbury, R. C., Univ. of Wisc.
4592 Pritchard, J. F., Cornell Univ.
4593 Barton, C. R., Stevens Institute.
4594 Teble, C. J., Cornell University.
4595 Takata, I., Univ. of Arkansas.
4596 Hazle, J. C., Penn. State College.
4597 Wuebker, C. L., Case School Sci.
4598 Erickson, G. C., Arm. Inst. Tech.
4599 Staehle, P. M., Univ. of Wisconsin.
4600 Brown, G. O., Univ. of Kansas.
4601 Greene, P. W., Yale University.
4602 Missirian, W. K., Yale University.
4603 Hastings, E. S., Yale University.
4604 Beck, B. C., Yale University.
4605 MacArthur, J., Yale University.
4606 Chung, D. M., Yale University.
4607 Lynge, C. M., Yale University.
4608 Seltzer, D., Yale University.
4609 Patterson, W. H., Yale University.
4610 Thompson, W. H., Yale Univ.
4611 Griswold, S. A., Yale Univ.
4612 Rich, W. L., Jr., Yale University.
4613 Shallenberger, J. W., Yale Univ.
4614 Leavenworth, J. P., Yale Univ.
4615 Carter, R. E., Yale Univ.
4616 Sharon, R. A., Yale University.
4617 Rous, C. C., Univ. of Toronto.
4618 Kendall, G. W., Kan. St. Agr. Coll.
4619 Fenton, H. H., Kan. St. Agr. Coll.
4620 Gish, K., Kansas St. Agr. Coll.
4621 Reed, C. J., Kan. State Agr. Coll.
4622 Fickel, G. R., Kan. St. Agr. Coll.
4623 Stannard, G. A., Kan. St. Agr.Coll
4624 Bradford, F. S., Kan. St. Agr. Coll.
4625 Brandt, D. G., Kan. St. Agr. Coll.
4626 Cooke, E. R., Kansas St. Agr. Coll.
4627 Miller, E. D. C., Kan. St. Agr.Coll.
4628 Livingston, F.B., Kan.St.Agr.Coll.
4629 Miller, V. E., Kan. St. Agr. Coll.
4630 Hobbs, M. H., Univ. of Kansas.
4631 deGoicoechea,L., Mass. Inst. Tech.
4632 Katzenstein,L.L., Mass.Inst.Tech.
4633 Schumann, J. H., Univ. of Mich.
4634 Burnham, A. E., Univ. of Mich.
4635 Parshall, D. I., Univ. of Mich.
4636 Gokay, W. M., Univ. of Mich.
4637 Ottmer, H. G., Univ. of Mich.
4638 Brewer, R. T., Univ. of Mich.
4639 Martinck, J. A., Univ. of Mich.
4640 Roth, J. E., Univ. of Michigan.
4641 Carlson, A., Univ. of Mich.
4642 Carlson, R. E., Univ. of Mich.
4643 Foote, A. A., Univ. of Mich.
4644 Daly, R. J., Univ. of Mich.
4645 Richards, N. J., Univ. of Mich.
4646 Binney, R. L., Univ. of Mich.
4647 Sheppard, H. S., Univ. of Mich.
4648 Goldman, M., Univ. of Mich.
4649 Heald, W. S., Univ. of Mich.
4650 Dicker, A. O., Univ. of Mich.
4651 Thierwechter, E., Univ. of Mich.
4652 Driy, J. A., Univ. of Mich.
4653 Rose, D. H., Purdue University.
4654 Ransbury, H. R., Purdue Univ.
4655 Parsons, J. B., Purdue University.
4656 Moon, W., Purdue University.
4657 Klippel, W. P., Purdue Univ.
4658 Klein P., Purdue Univ.
4659 Kelso, N. T., Purdue Univ.
4661 Girard, S. G., Purdue Univ.
4662 Fitch, R. H., Purdue Univ.
4663 Brearley, D., Purdue Univ.
4664 Danielson, O. H., Purdue Univ.
4665 Childress, W., Purdue Univ.
4666 Dalton, F. K., Univ. of Toronto.
4667 Eppler, H. G., Texas A. & M. Coll.
4668 Williams,W.T., Texas A.& M.Coll.
4669 Sherley, A., Texas A. & M. Coll.
4670 Chaney, L. P., Texas A. & M. Coll.
4671 Shropshive,L.O.,TexasA.&M.Coll.
4673 Broyles, G., Texas A. & M. Coll.
4674 Collins, A. B., Texas A. & M. Coll.
4675 Samuels, I. H., Lehigh Univ.
4676 Nixon, C. G., Ohio Northern Univ.
4677 Yates, J. E., Wash. State Coll.
4678 Kimbell, C. L., Georgia Sch. Tech.
4679 Franks, W. T., Ohio North'n Univ.
4680 Wright,H.H.L.,OhioNorthernUniv
4681 Johnston,J.C.,OhioNorthern Univ.
4682 Graetz, W. C., Univ. of Wisconsin.
4683 Byron, E., Stevens Inst. Tech.
4684 Karr, A. D., Stevens Inst. Tech.
4685 Manegold, J. R., Univ. of Wisc.
4686 Smith, R. H., Ohio Northern Univ.
4687 Roberts, L. A., Ohio North'n Univ.
4688 Steinmetz, C. K., Penna. St. Coll.
4689 Meyer, H. J., Ohio Northern Univ.
4690 Belding, A. V. Ohio North'n Univ.

Digitized by Google

4691 Joseph G. C., Ohio North'n Univ.
4692 Kreidiv, R. H., Penna. St. Coll.
4693 Miller, F. C., Throop Poly. Inst.
4694 Kojan, J., Case Sch. Applied Sci.
4695 Faunce, K. W., Mass. Inst. Tech.
4696 Macaulay, R. V., Univ. of Toronto
4697 Reinhard, A. J., Worc. Poly. Inst.
4698 Sutton, J. F., Penna. State Coll.
4699 Frankenberry, T. H., Ohio Northern Univ.
4700 Hull, F. D., Univ. of Illinois.
4701 Grever, G. L., Univ. of Illinois.
4702 Warth, E. C., Univ. of Wisconsin.
4703 Waddington, C. V., Univ. of Kan.
4704 Turner, F. F., Ohio North'n Univ.
4705 Burnley, H. W., Ohio Northern Univ.
4706 Atkinson, K., Cornell University.
4707 Blood, H. L., Cornell University.
4708 Dawkins, D. C., Cornell Univ.
4709 Ferris, O. C., Cornell University.
4710 Hannam, G. C., Cornell Univ.
4711 McBride, F. R., Cornell Univ.
4712 Morris, G. T., Cornell Univ.
4713 Morbio, A., Cornell University.
4714 Perry, L. J., Cornell University.
4715 Rogers, A. L., Cornell University.
4716 Rothinater, O., Cornell Univ.
4717 Schiff, M., Cornell University.
4718 Taylor, R. S., Cornell University.
4719 Wambaugh, R. H., Cornell Univ.
4720 Morningstar, B. F., Univ. of Mich.
4721 Ballard, H. L., Univ. of Mich.
4722 Parsons, H. E., Univ. of Mich.
4723 Mack, E. A., Univ. of Mich.
4724 Dikkers, G., Univ. of Mich.
4725 Eckert, O. E., Univ. of Mich.
4726 Hayes, D. W., Univ. of Mich.
4727 Finley, C. J., Columbia Univ.
Total, 163.

The American Society of Mechanical Engineers

ANNUAL MEETING DECEMBER 5–8, 1911

The Annual Meeting of the American Society of Mechanical Engineers will be held in the Engineering Societies Building, New York, December 5-8, 1911.

Among the many interesting subjects on which papers will be read are included those of textiles, cement manufacture, machine shop practice, steam boiler performance, and oil engines.

Aside from the professional sessions many pleasant social features have been planned among the principal of which will be the President's Reception on Tuesday evening in the rooms of the Society, and the annual re-union of the membership of New York in honor of the newly elected officers and visiting members, which will be held in the Hotel Astor Thursday evening. Several excursions have also been planned which include an inspection of the S. S. Olympic of the White Star Line, a trip to the Brooklyn Navy Yard, and an Inspection of the Bush Terminal Buildings in Brooklyn.

The welcoming of the visiting ladies will be in charge of the ladies of New York, who have organized a committee to plan for trips and entertainment of various descriptions.

Annual Meeting of the Chemical Engineers, Washington, D. C., December 20-22, 1911

The American Institute of Chemical Engineers will hold its fourth annual meeting in Washington, D. C., December 20-22, 1911, with headquarters at the New Willard Hotel. The meeting will be opened with a business session on Wednesday, December 20, at 9.30 a.m. and the reading of technical papers is scheduled to commence at 10.30 a.m. An attractive program has been prepared comprising a large number of papers covering a varied field of subjects in chemical engineering. Aside from the papers there is scheduled a number of interesting trips or excursions to various points of interest including a visit to the Bureau of Standards, the U. S. proving grounds at Indian Head, Md., the steel plant at Sparrows Point, Baltimore and the cement plant of the Tidewater Portland Cement Company.

A subscription dinner will be given in the new Willard Hotel at 7.00 p.m., Thursday, December 21, and Friday December 22, at 2.30 p.m. President Taft will receive the members of the

Digitized by Google

Institute in the East Room of the White House.

Cost of and Rates for Electric Service

At the second regular meeting of the University of Michigan Branch of the A. I. E. E., held on November 8, Mr. B. J. Denman, acting chief engineer of the Detroit Edison Company, presented a paper on "Cost of and Rates for Electric Service." Mr. Denman explained the division of "cost" into "fixed charges" and "running expenses." Fixed charges included interest on investment, depreciation of property, office expenses, and insurance. Running expenses included operating cost and maintenance, maintenance taking of minor alterations and repairs not chargeable to depreciation. The amount to be set aside each year to cover depreciation is based upon the estimated useful lifetime of the equipment. It may either be placed in a bank as a reserve fund or invested in the property. Three reasons given for "junking" equipment were "wear," "obsolescence", and "inadequacy." The latter does not always justify junking a piece of machinery, because it might be in good operating condition and therefore have a second-hand value which is greater than its value as junk.

Rates should be such as to pay cost of service and a reasonable profit. Too large a profit is detrimental, since it induces competition, and promotes ill feeling among consumers, thus impeding growth of business.

Mr. Denman explained how "consuming districts" were analyzed to find the cost of delivering energy; such cost including a proper apportionment of fixed charges and running expenses. Thus the cost per kilowatt of demand is calculated, and the cost per kilowatt delivered, for the different classes of service. A diversity factor is arrived at from such an analysis and the fixed cost per kilowatt of demand divided by the diversity factor gives a basis upon which rates are determined. The different classes of service, light and power, are considered separately in such an analysis.

A wholesale rate is applicable where a large consumer takes primary current, supplying his own transforming and switchboard equipment. The rate is lower than that made to the ordinary consumer, since the fixed costs connected with the delivery of power under these conditions is much less.

Under a so-called "limited service contract" the customer agrees to take no power at certain specific hours, the said hours being those of the central station peak loads, and gets a correspondingly low rate, since the central station and transmission lines do not require extra equipment to stand ready to serve him when the peak loads are on.

The John Fritz Medal

The John Fritz Medal for 1911, which was awarded to Sir William Henry White for "notable achievements in naval architecture," was presented to the recipient of the honor at the dinner of the Society of Naval Architects and Marine Engineers, at the Waldorf-Astoria Hotel, New York, on Friday evening, November 17, 1911.

The presentation address was made by Onward Bates, president of the Board of Award of the John Fritz Medal, and Sir William in responding paid a high tribute to John Fritz, now in his 89th year, who was present at the dinner.

The attendance included representatives of the principal engineering societies of the United States.

The Board of Award consists of sixteen members, four each from the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the American Institute of Electrical Engineers. The present members representing the A. I. E. E., are Messrs. Henry G. Stott, Louis A. Ferguson, Lewis Buckley Stillwell, and Dugald C. Jackson.

Digitized by Google

Previous awards of the Medal were made as follows:

In 1905 to Lord Kelvin.
1906 to George Westinghouse.
1907 to Alexander Graham Bell.
1908 to Thomas Alva Edison.
1909 to Charles T. Porter.
1910 to Alfred Noble.

Past Section Meetings

Atlanta

The Atlanta Section held its opening meeting for this season on October 31. Eighteen members were present. The following officers were elected for the year 1911–1912: Chairman, A. M. Schoen; vice-chairman, W. C. Coles; secretary-treasurer, H. M. Keys; managers, George J. Yundt, E. P. Peck, C. P. Wood, J. St. F. Davenport. No paper was presented at this meeting.

Baltimore

The first meeting of the Baltimore Section was held in the physical laboratory of the Johns Hopkins University on Friday evening, October 20. Dr. J. B. Whitehead gave a report of the Sections conference at the Chicago convention of the Institute, after which the Institute papers, appearing in the March PROCEEDINGS, entitled "Comments on Fixed Costs in Industrial Power Plants", by John C. Parker, and "The Cost of Industrial Power", by A. E. Hibner, were reviewed by Dr. Whitehead and Mr. Loizeaux. A discussion followed both papers. Thirty-seven members were present.

Boston

The Boston Section held its first meeting on October 18, in coöperation with the Boston Branch of the American Society of Mechanical Engineers, and the Boston Society of Civil Engineers. A paper was presented by Mr. Fred. A. Wallace, entitled "The Power System of the Pacific Mills." At the executive session of the Boston Section the following officers were elected for the current year: Chairman, William L. Hooper; vice-chairman, Frederic P. Valentine; secretary-treasurer, G. A. Rodenbaeck; executive committee, N. J. Neall, William Wickenden, J. W. Cowles, and J. H. Libbey. Two hundred and twenty members of the three societies attended the meeting.

The November meeting of the Boston Section was also held jointly with the Boston Society of Civil Engineers and the Boston Branch of the American Society of Mechanical Engineers. The total attendance numbered 160 members of the three societies. A paper entitled "Some Refractory Substitutes for Wood" was read by Professor S. L. Norton, of the Massachusetts Institute of Technology.

Chicago

A joint meeting of the Chicago Section with the Electrical Section of the Western Society of Engineers was held on the evening of October 25, and was the occasion of the annual lecture by Dr. Charles P. Steinmetz. Mr. Bion J. Arnold, past-president of both societies, introduced the speaker. The subject of the lecture was "Reactance in Alternating-Current Circuits", and Dr. Steinmetz presented it in his usual lucid and entertaining style to the audience of over 500 engineers who had gathered and completely filled the hall.

Cleveland

The regular monthly meeting of the Cleveland Section was held on October 23. The attendance numbered 105 members and visitors. Mr. F. S. Lewis, who represented the Cleveland Section at the Chicago convention, submitted his report. This was followed by two papers; one entitled "Industrial Lighting", by Mr. C. L. Eschleman, of the Adams Bagnall Electric Company, and the other, "Choosing an Illuminant", by Mr. Irving H. Van Horn, of the National Electric Lamp Association.

Mr. Eschleman discussed the efficiency of illumination from the standpoint of its influence on factory produc-

Digitized by Google

tion. It was brought out that the cost of efficient lighting is an insignificant percentage of the total cost of production; that it could easily be repaid by the increased output and by the prevention of accidents, and that from the high efficiency illuminants now available it is possible to select the one best suited to any particular requirement.

Mr. Van Horn dealt principally with the uses of tungsten filament lamps for illuminating purposes.

The papers were discussed by Professor H. B. Dates, and Messrs. Wallau, Lincoln, Henniger, Eschleman, and Edwards.

Detroit–Ann Arbor

The regular monthly meeting of the Detroit–Ann Arbor Section was held in the University of Michigan, Ann Arbor, on October 28, with Professor C. L. De Muralt presiding, and a total attendance of 56 members. A paper was read on "The Use of Imaginary Quantities in Electrical Engineering."

Los Angeles

The Los Angeles Section held its opening meeting for the year 1911-1912 at Hamburger's Cafe, Los Angeles, on October 17, 1911. There were present 122 members and visitors, including members of the Engineers and Architects Association, who had been invited to take part in the meeting. Mr. J. E. Macdonald, the retiring chairman, after thanking the members for their cooperation during the last year, introduced Mr. O. H. Ensign, chairman-elect for the year 1911–1912. Mr. Ensign announced the appointment of the following committees for the year: Executive, E. R. Northmore, secretary, C. G. Pyle, assistant secretary, J. A. Lighthipe, R. H. Manahan, E. F. Scattergood, J. E. Macdonald; papers, entertainment, membership and discussion. The chairmen of the respective committees were introduced and made brief remarks. Mr. Ensign then introduced Dr. James A. B. Scherer, the speaker of the evening, who gave an address on "Technical Education from the Practical Standpoint." Dr. Scherer's address was followed by talks by G. A. Damon and B. F. Pearson.

Pittsburgh

The Pittsburgh Section held its regular monthly meeting in the auditorium of the Engineers Society of Western Pennsylvania on November 14. About 100 members were present. A paper entitled "Shop Test of Electrical Apparatus" was presented by Mr. E. M. Olin, of the Westinghouse Electric and Manufacturing Company. Among those who took part in the discussion were: Messrs. P. M. Lincoln, A. M. Dudley, C. W. Copley, S. Lavine, R. L. Wilson, M. C. Turpin, H. E. Kennedy, E. Chesrown, H. R. Stewart, and M. F. Sellects. At the close of the discussion Mr. K. C. Randall gave an outline of the proposed work of the Pittsburgh Section for the current year.

Pittsfield

Mr. Percy H. Thomas, consulting engineer, of New York, addressed the Pittsfield Section at its second regular meeting for the year, held on November 10, on "Some Features of the High Tension Transmission of Power." Eighty engineers were present. Mr. Thomas' address dealt with two phases of high tension transmission work; namely, suspended conductors on suspension insulators, and public service utilities' franchises. In discussing the first subject Mr. Thomas described the factors governing the proper calculation and design of high tension transmission with special reference to the suspension type of insulator. The consideration of the stresses in the conductors and the effects of temperature, ice and wind were covered. The effect of high potential waves and the conditions affecting the proper spacing of the conductors were also discussed. In his second topic Mr. Thomas discussed public service utilities' franchises from the point of view of the capitalists and the public.

Digitized by Google

An informal dinner at the Hotel Wendell preceded the meeting, with Mr. Thomas as the guest of honor.

Portland, Oregon

The Portland Section held its first meeting of the year in the assembly hall of the Electric Building, Portland, Oregon, on Tuesday evening, October 17. This being the first meeting, there was a considerable volume of business to be transacted. The executive committee was authorized to obtain a preliminary list of papers suitable for the proposed Pacific Coast Convention of the Institute, authorized to be held in Portland during the month of April. A committee was appointed to arrange for a monthly dinner or luncheon for the purpose of affording facilities for the members to get together and promote good fellowship. It was voted to appoint a library committee to confer with the library association in the building of the new public library, with view to obtaining better accommodations to serve the needs of technical men. There was a general sentiment that more technical books should be on file in the library and that they should be so arranged as to be more readily accessible for use. Mr. H. A. Kirkland, delegate of the Portland Section to the Institute's Chicago convention, gave a report of his trip and the proceedings of the convention.

At the conclusion of the business Mr. W. D. Scott presented the paper of the evening, entitled "Plant Valuations." The paper dealt more particularly with the theory of depreciation in plants. The author called attention to the necessity of having one plant valuation for the purpose of taxation, and another valuation for the issuance of securities.

Twenty-seven members attended the meeting.

St. Louis

The St. Louis Section held its regular monthly meeting at the Engineers' Club, St. Louis, on November 8. Seventy-eight members were present. A description of the distributing system of the union Electric Light and Power Company was given by Mr. K. H. Hansen, chief electrical engineer of that company. Beginning with the apparatus in the main generating stations, the various features of the apparatus from the 6,600-volt, 25-cycle generators, to the customers' service connections were described and illustrated by lantern slides. Direct current is distributed to customers within a limited area in the business district at 115, 230 and 500 volts, the last being necessary on account of a number of 500-volt direct-current elevator motors installed. The outlying districts are supplied with 2,300-volt, 60-cycle alternating current from synchronous motor generator sub-stations, and this voltage is stepped down to 115 and 230 volts by transformers located near the customer's premises. The 60-cycle feeders from the sub-station are three-phase, four wire, and distribute current as single-phase feeders for lighting service and three phase for larger power. The three phases of each four wire feeder are regulated in the substation as individual single-phase feeders. In connecting motors to the company's lines, their rule is that direct-current motors of one horse-power and larger must be for 230 volts, while less than that may be 115 volt. Alternating-current motors up to 10 horse-power may be single-phase, 230 volt, with starters. Above that size three-phase motors must be used. Motors above 25 horse-power must be of the wound rotor type. Among those taking part in the discussion were Messrs. Hobein, Clarkson, Langsdorf and Humphrey.

San Francisco

The San Francisco Section held its regular monthly meeting on October 28. Mr. C. F. Elwell presented a paper on "High Tension, Direct Current Transmission." The paper contained very complete data on the subject gathered by Mr. Elwell during recent visits in Europe, and brought out numerous

Digitized by Google

advantages of high tension transmission for great distances and high voltages. The meeting was unusually well attended and much interest was shown in the discussion.

Schenectady

The Schenectady Section opened the season of 1911–1912 with an informal smoker at the Mohawk Golf Club on November 2. Approximately 400 members and guests were present. The smoker was opened about 8:15 p.m. by Mr. E. B. Merriam, chairman of the Section, who made a brief speech of welcome and gave an outline of the program planned for the season. After several well chosen selections by the orchestra a photograph was taken of the assembled guests for reproduction in the local press. Addresses then followed by Dr. Charles P. Steinmetz, Mr. W. B. Potter, and Mr. Ralph W. Pope. Telegrams were received from Mr. Gano Dunn, president of the Institute, Mr. W. C. Fish, manager of the Lynn works of the General Electric Company, and Mr. E. W. Rice, vice-president of the General Electric Company, expressing regret at their inability to attend. Immediately following the addresses, upon a specially constructed stage complete with curtains and drops, footlights and other theatrical appurtenances, the Jest and Song Club presented a minstrel performance. After the performance the Union College Glee Club, of 30 men, contributed to the evening's amusement by the singing of popular college songs. Both sets of performers received the most enthusiastic applause. For the next hour the guests entertained themselves with general conversation and the renewal of friendships. The smoker concluded with an informal reception which was held by Chairman Merriam and other prominent men who were present as guests of the Section.

The first regular meeting of the Schenectady Section was held on November 8. Chairman E. B. Merriam presided, and about 250 members were present. Mr. Merriam introduced Mr. Henry M. Hobart, consulting engineer with the General Electric Company, who presented a paper on "Some Simple Dormant Possibilities in Electrical Engineering." Mr. Hobart discussed the subject under the following heads: Induction generators; Diesel engines; alternator voltages; static rectifiers; rotary converters; ventilating schemes; electric propulsion of ships. The paper was discussed by Messrs. D. B. Rushmore, F. P. Coffin, E. A. Baldwin, C. J. Hixon, F. W. Peek, C. MacMillan, A. H. Kruesi, J. R. Werth and L. T. Robinson.

Seattle

The regular monthly meeting of the Seattle Section was held on October 21. The whole evening was occupied with plans for the season and other business Thirty-six members were present and took part in the general discussion.

Toledo

The regular monthly meeting of the Toledo Section was held on Friday evening, November 3, at the Toledo Commerce Club. Mr. C. E. Wise, Detroit Manager of the Cutter Electric and Manufacturing Company, addressed the members on the subject of "Circuit Breakers." Mr. Wise explained the various types of I-T-E circuit breakers, including the reversal features. A circuit breaker was on exhibition, and the oil film time limit feature was shown. The address was followed by a discussion which was participated in by Messrs. Kirk, Gilmartin, Mathews, Hill, Halford, Grah, O. Neuber and M. Neuber.

Vancouver, B. C.

The newly authorized Vancouver Section held its first meeting on October 13, 1911. Twenty-four members and associates were present. The following officers were elected for the year: Chairman, F. D. Nims; secretary, E. M. Breed; executive committee, F. D.

Digitized by Google

Nims, E. M. Breed, L. G. Robinson, John R. Read, A. C. Routh. This meeting being held for the purpose of organization, no paper was presented.

The second meeting of the Section was held on Friday, November 10. A set of by-laws drawn up by the executive committee were adopted, and it was decided that regular monthly meetings would hereafter be held on the first Friday of each month. A paper was then read by Mr. L. G. Robinson, engineer with the British Columbia Electric Railway Company, on "The Generating and Transmission Systems of the British Columbia Electric Railway Company."

WASHINGTON, D. C.

At the November meeting of the Washington Section a paper on "The Navy's Coast Signal Service" was presented by Lieutenant-Commander D. W. Todd, stationed at the Navy Department, Washington. Commander Todd described clearly the present policy and practice of the Navy Department in operating its three classes of wireless stations; namely, the high power, the medium power, and the low power stations.

The first of the high power stations is that now building on a part of the Fort Myer Reservation in Virginia, a few miles from Washington. This will be known as the Arlington Station and will be placed in service next year.

The great need for legislation providing for the regulation of those operating wireless equipment was clearly pointed out by the speaker. He also expressed his conviction that in the true field of wireless—for communication over the sea, and between points not already connected by land or cable lines—there is a bright future for wireless operation, and among a long list of inventions or developments which the Navy now needs to make its wireless service more comprehensive and useful, and which the speaker expects will in due time be provided by those engaged in the development and manufacture of wireless equipment, it was interesting to note that an aeroplane wireless telegraph set was included.

The meeting was held as usual in the Telephone Building and there was a large number of members and guests in attendance.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch reorganized for the year at a meeting held on October 24, and the following officers were elected: Chairman, W. B. Stelzner; student chairman, F. Oneal; secretary, L. R. Hulse; treasurer, C. F. Spangler. The chairman appointed as a program committee Messrs. G. M. Campbell, T. M. Northum, M. P. Watts, and G. W. Schalchlin. Professor W. B. Stelzner made a report of the Institute's Chicago convention last June. Mr. W. R. Purcell then read a paper by Mr. W. S. Bayley describing a dynamo designed for a mining company in India.

A special meeting of the Branch was held on October 30. Mr. P. L. Mardis presented a paper on "Wireless Telegraphy." Mr. Mardis did post graduate work last year in the University of Arkansas, and his paper was the result of research work done by himself and Mr. F. S. White, who is also connected with the university.

The Branch held its third meeting on November 7. Mr. W. R. Purcell presented an abstract of the Institute paper appearing in the October PROCEEDINGS, entitled "A Theory of Commutation and Its Application to Interpole Machines", by B. G. Lamme. Mr. F. L. Oneal then gave his experiences in telephone work last summer.

BUCKNELL UNIVERSITY, LEWISBURG, PA.

The Bucknell University Branch held its first meeting for the year on October 27, with Professor W. K. Rhodes in

Digitized by Google

the chair, and an attendance of 60 members. A paper entitled "The Organization and work of the National Bureau of Standards" was read by Professor J. C. Hostetter, who is an assistant chemist in the employ of the Bureau.

Colorado State Agricultural College

The regular meeting of the Colorado State Agricultural College Branch was held in the electrical engineering building on Tuesday evening, October 24. The X-ray machine was discussed and demonstrated by Professor Persons. Geissler tubes were also shown in operation, and the different rays defined.

The Institute paper on "Modern Automatic Telephone Apparatus", by W. Lee Campbell, was reviewed and discussed by Mr. A. A. Catlin.

University of Colorado

A special meeting of the students of the University of Colorado was held on November 1, under the auspices of the University of Colorado Branch, in order that the students could hear an address by Mr. F. W. Frueauff, vice-president and general manager of the Denver Gas and Electric Company, on "The Needs and Opportunities of the Engineer in the Business World." Approximately 225 students attended the meeting.

Kansas State Agricultural College

This Branch held its regular monthly meeting on November 7. Mr. W. O. Pennell, chief engineer of the Missouri and Kansas Telephone Company, gave an illustrated lecture on "Telephone Engineering." Mr. Pennell's lecture dealt chiefly with the construction of buildings and lines.

University of Kansas

The regular monthly meeting of the University of Kansas Branch was held on October 25. Mr. Holliday, of the Lawrence Home Telephone Company, gave a talk on "General Problems in Telephone Plant Management."

Mr. Winsten, of the Kellogg Switchboard and Supply Company of Chicago, gave a talk on a similar subject as that of Mr. Holliday, and also described some tests which were made in Pittsburgh and St. Louis as to the average length of conversation over the telephone. This average was 99+ seconds.

At a meeting held on November 15 the Branch was addressed by Mr. E. L. Bray, who described his inspection trip over the plants of the Indiana Steel Company at Gary, Ind., the Allis-Chalmers Company, Milwaukee, Wis., the Western Electric Company, Chicago, and the generating stations of the Commonwealth Edison Company of Chicago.

State University of Kentucky

The first meeting of the State University of Kentucky Branch for this season was held on November 7. The program consisted of a paper by Professor W. A. Freeman, on "Some Developments in Long Distance Telephony." Messrs. Hollar and Ammerman contributed to a discussion on motors and switchboards.

University of Michigan

The University of Michigan Branch held its first meeting on October 25. Professor A. R. Sawyer, of the electrical engineering department, gave an address on "Electrical Progress." Professor Sawyer pointed out the important part which the Edison lamp has played in the development of commercial electrical machinery. He explained how the inability to get farm laborers, and the inefficiency of animal labor in general would compel farmers to adopt electrical power more generally than they have done; and showed that a proper arrangement of buildings would be necessary in order to bring about desirable results.

Digitized by Google

University of Missouri

The University of Missouri Branch held its regular meeting on October 23. The subject of the meeting was "Increasing the Power Sales for Central Station Companies." The speakers were Messrs. C. A. Whipple and E. M. See. Mr. Whipple took up the opportunities of the employes of the companies to secure business, and how such individual solicitation could be encouraged by the companies. Mr. See described the methods adopted by various companies and the results attained. Messrs. Beckman, Guengerich, Buergey, Huston Kennard, Kellogg, and Professor Shaw, took part in the discussion.

N. C. College of A. and M. Arts

The North Carolina College of Agriculture and Mechanic Arts Branch reorganized at a meeting held on November 17, and the following officers were elected: Chairman, E. P. Speer; secretary, W. H. Graham; executive committee, the chairman and secretary, and Professor William Hand Browne, Jr.

Oregon Agricultural College

This Branch held its first meeting on October 24, and the following officers were elected for the year: Chairman, H. Belknap; secretary-treasurer, W. R. Varner; executive committee, Professors W. A. Hillebrand and E. R. Shepard, Dr. W. Weniger, and Messrs. F. E. Ewart and L. F. Wooster. The principal feature of the evening's program was a talk by Professor Hillebrand on "Experiences in Building a High Tension Line."

Rensselaer Polytechnic Institute, Troy, N. Y.

The first meeting of the Rensselaer Polytechnic Institute Branch for the year was held on November 2, with an attendance of 63 members and visitors. Professor Charles F. Scott, of Yale University, formerly with the Westinghouse Electric and Manufacturing Company, Pittsburgh, and Past-President of the A. I. E. E., was the guest and speaker at the meeting, and addressed the students on the subject "The Opportunities of a Young Engineer." The meeting was followed by a smoker.

Stanford University, Cal.

A meeting of the Stanford University Branch was held on October 19. A number of new members were admitted to the Branch and several other business matters were transacted, after which an illustrated talk was given by Mr. Koontz regarding his experiences with the Northern Power Company.

Throop Polytechnic Institute, Pasadena, Cal.

A meeting of this Branch was held on October 23. Mr. O. H. Ensign, chief electrical engineer of the United States Reclamation Service, gave a talk on the work of the reclamation engineer. The Salt River project and others were described.

University of Vermont

The University of Vermont Branch held its first meeting for the school year on October 25, in the Williams Science Hall. The following officers were elected for the year: Chairman, Professor W. L. Upson; vice-chairman, C. H. Adams; secretary, O. Krupp; treasurer, H. S. Batchelder. The business session was followed by an interesting lecture on "Mechanical Engineering", by Professor Robinson. Professor Robinson discussed various phases of the subject, going into the theory of efficiency and the relations between labor and capital. He showed by means of curves and diagrams the effect the steam engine has had on civilization.

On November 15, Professor C. W. Mixter gave a lecture before the Branch on "Scientific Shop Management", dealing with the shop management known as the Taylor system. The speaker first compared unsystematic management with scientific manage-

Digitized by Google

ment. He then gave an outline of the Taylor system. He also spoke of methods of paying wages. Forty-one members attended the meeting.

WASHINGTON UNIVERSITY, ST. LOUIS, MO.

The Washington University Branch held its opening meeting on October 26. Officers for the year were elected as follows: Chairman, Irwin L. Cheney; vice-chairman, E. T. Nipher; secretary-treasurer, P. S. Stevens.

WORCESTER POLYTECHNIC INSTITUTE

At its meeting held on November 14, the Worcester Polytechnic Institute Branch was addressed by Albert S. Richey, professor of electric railway engineering, on "A Job Ahead of the Nickel", the subject relating to the financial aspect of the electric railway proposition in New York City. On a map suspended at the front of the hall the speaker outlined New York City in colored chalk. Next, the principal surface, elevated and subway lines now in course of construction were sketched in. The cost of the lines was next arrived at and comparisons made with the cost of the Panama Canal and the total valuation of Worcester, showing that the transportation problem in New York during the next five years would call for as much capital outlay as would build two Panama Canals or the building of four towns like Worcester.

YALE UNIVERSITY, NEW HAVEN, CONN.

The newly authorized Yale University Branch organized at a meeting held on October 19. A constitution and by-laws were adopted, and the following officers were elected for the year: Chairman, B. C. Beck; secretary, J. W. Shallenberger; treasurer, J. MacArthur; governing board, Professor Charles F. Scott, S. A. Griswold and E. S. Hastings; librarian, D. M. Chung; executive committee, the first three officers named and the governing board, with Professor Scott as chairman of the committee. Meetings are to be held every alternate Friday evening of the college year. It is planned to have outside speakers at least once a month.

The first regular meeting of the Branch was held on October 27. Professor Scott gave a talk on the Institute and its Branches. In addition he took up several fields of electrical engineering which are offering large opportunities for expansion and development.

Twenty-five students and six members of the faculty were present.

The second regular meeting of the Branch was held on Friday, November 17, with Chairman Beck presiding. A paper on "Tungsten Lamps" was presented by Mr. J. W. Shallenberger, who illustrated it by several experiments which showed the difference between tungsten and carbon filament lamps. Mr. S. A. Griswold read a paper on "Power in the Machine Shop," with particular reference to that part of the subject relating to individual and group drive.

Personal

MR. H. T. CASE has resigned as technical writer with the General Electric Company at Schenectady, N. Y., to enter the employ of the Hydro-Electric Power Commission of Ontario, Toronto, Ont.

MR. C. GORDON COX, formerly of the apparatus sales department, General Electric Company, St. Louis, Mo., has been appointed sales manager for Burch-Sulzer Brothers, Drexel Engine Company, of St. Louis, Mo.

MR. ETIENNE DE FODOR, general director of the Budapest General Electric Company, was recently given a banquet in honor of his thirtieth anniversary as an electrical engineer. The banquet was attended by members of the government and municipality and a large number of engineers.

Digitized by Google

MR. J. H. SIEGFRIED has been appointed superintendent of the city light and power department of the City of Winnipeg, Man., the appointment having been made October 1. Mr. Siegfried was formerly in charge of the operating department of the United Missouri River Power Company of Helena, Montana.

MR. E. HENKHE, formerly in the designing department of the British Westinghouse Electric Company, Manchester, England, has accepted a position as technical writer with the International Correspondence Schools, and is located in their Spanish text-book department, at 4 West 22nd Street, New York City.

MESSRS. G. LOBO and J. H. SHEARER will head the technical staff of the Kelvin Engineering Company, 78 Wall Street, New York, a company recently incorporated for the purpose of doing a general engineering and contracting business. Mr. Lobo was formerly partner and chief engineer with Victor M. Braschi and Company, of Mexico City.

Obituary

MR. EDGAR WOODS MIX, a Member of the Institute, was drowned in the English Channel on the evening of November 12. Mr. Mix was born in Columbus, Ohio, on February 4, 1867. He graduated from the Ohio State University in June, 1888, with the degree of B.S. In August of that year he entered the employ of the Thomson-Houston Company, where he did work of various kinds inside and outside of the factory. In July, 1889 he took up the recording watt meter and conducted that department of the Thomson-Houston works until the regular organization of that department in May 1890. In August 1890 he went to Paris in connection with a watt-hour meter contest and established a factory there for building watt-hour meters for the Thomson-Houston International Electric Company. He occupied the position of chief engineer of this firm until the first of November, when he resigned to become manager of the European division of the General Motors and Export Company. Mr. Mix became an Associate of the Institute on September 3, 1889, and was transferred to the grade of Member on March 20, 1895. Mr. Mix was also interested in aeronautics, and won the race for the Coupe Internationale des Aeronautes by flying from Zurich, Switzerland, on October 5, 1909, to a point near Warsaw, 696 miles, and he had been chosen delegate to the international aviation conference which opened in Rome on November 25, 1911. Mr. Mix was unmarried.

MR. CARYL D. HASKINS, manager of the lighting department of the General Electric Company, Schenectady, N. Y., died from pneumonia in Salt Lake City, Utah, on November 18, after a brief illness. Mr. Haskins was born at Waltham, Mass., on May 22, 1867. His preliminary education was acquired in public and private schools in the United States and England, and his technical education by private study. His first position was with the firm of Haskins, Davis and Company, mechanical engineers, of London, where he gained valuable experience in general machinery, gas engines, and in patent practice. Later he entered the employ of Mr. S. Z. De Ferranti of London, and had charge of Mr. Ferranti's meter department. About a year later he returned to America, and in November, 1889 he accepted a position with the Thomson Electric Welding Company as draftsman and did original work on the design of automatic welding machines. Several months later he was transferred to the Thomson-Houston Electric Company, in charge of all the outside work in connection with meters, acting also as engineer for this work. In 1891 he became general manager of the meter department. During the latter part of 1892 he was appointed

Digitized by Google

manager of the General Electric Company's meter and instrument department. At the time of his death, he was manager of the lighting department. Besides contributing a large number of papers on engineering subjects to various technical journals, Mr. Haskins was also the author of several valuable works on transformers, and a contributor to the Institute PROCEEDINGS. He was also an inventor of some note, having been granted patents on transformer, switch, automatic switch control, and improvements in meters. He invented an auto-dirigible torpedo, and was an authority on coast defense and torpedo warfare. He served in the Spanish-American war as second in command of submarine mining operations in the Boston district. Mr. Haskins joined the Institute as an Associate on March 18, 1890, and was transferred to the grade of Member on June 20, 1894.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Association for the Advancement of Science Proceedings 58th meeting. n.p. 1908 (Gift of American Association for the Advancement of Science.)

American Institute of Electrical Engineers. Publications including contents of TRANSACTIONS and index of authors from Vol. 1–29, inclusive, 1884–1910. New York, 1911. (Gift of A. I. E. E.)

American Street and Interurban Railway Association. Proceedings 1910. (5 Vols.). New York, 1910. (Exchange.)

Congreso Cientifico (1° Pan Americano) Ciencias Economicas y Sociales. (Tomo III). Santiago de Chile, 1911.

——Ciencias Pedagogicas y Filosofia (Tomo I) Santiago de Chile, 1911. (Gift of Congreso Cientifico.)

Cyclopedia of Telephony and Telegraphy. Vols. 1–4. Chicago, American School of Correspondence, 1911. (Gift of Publishers.)

This is one of the series of text books used in the correspondence courses, and seems to have been carefully compiled, and well edited. It is profusely illustrated and well indexed. The teleautograph and telegraphone have short chapters.—W.P.C.

Design of Static Transformers. By H. M. Hobart. New York, D. Van Nostrand Co., 1911. (Gift of Publishers.) Price, $2.00 net.

This work deals with the practical application of the theory as set forth in the works of Fleming and Kapp. It contains a four-page bibliography of the important papers published since 1887.—W.P.C.

Direct and Alternating Current Manual, with Directions for Testing and a Discussion of the Theory of Electrical Apparatus. Ed. 2. By Frederick Bedell and C. A. Pierce. New York, Van Nostrand Co., 1911. (Gift of Publishers.) Price, $2.00 net.

The first edition, in 1909, has the title "Direct and Alternating Current Testing." A French edition is in preparation. Discussions of the induction motor, the induction generator, frequency changers, the synchronous motor and converter and wave analysis are given.

This well known laboratory manual is prepared with the idea of providing tests which can be carried out in any college laboratory, and the selection of such as are of primary importance and of undoubted pedagogical value, combining with these tests a statement of the underlying principles and showing in this way the significance of the results.—W.P.C.

Electric Traction and Transmission Engineering. By Samuel Sheldon and Erich Hausmann. New York, Van Nostrand Co., 1911. (Gift of Publishers.) Price, $2.50 net.

The authors, members of the American Institute of Electrical Engineers, have brought together in one volume of textbook size "a perspective view of a complete railway installation, from the cars to the power station, indicating the nature and sequence of the various entailed problems, and suggesting or illustrating methods for their solution."

Descriptive material is very sparingly used, the treatment being almost purely mathematical. Problems for solution by the student are appended to each chapter. The work is carefully indexed.—W.P.C.

Digitized by Google

Electric Central Station Distribution Systems, their Design and Construction. By H. B. Gear and P. F. Williams. New York, Van Nostrand Co., 1911. (Gift of Publishers.) Price, $3.00 net.

This volume is based on a series of articles in the *Electrical Age* during 1908 and 1909. It is designed to summarize in one volume, for the use of young engineers and students, the best American practice in distribution. The treatment is simple and direct, requiring only of the reader a general knowledge of electrical theory. The authors are associates of the American Institute of Electrical Engineers.—W.P.C.

Die Fortschritte auf dem Gebiete der Elektrischen Fernbahnen. By O. C. Roedder. Wiesbaden, 1909. (Purchase.)

Graphite, Vol. 6–8, 10–11. Jersey City, 1904–06, 1908–09. (Gift of Joseph Dixon Crucible Company.)

Handbook of Wireless Telegraphy, its Theory and Practice, for the use of Electrical Engineers, Students and operators. Ed. 3. By James Erskine-Murray. New York, D. Van Nostrand Co., 1911. (Gift of Publishers.) Price, $3.50 net.

This third edition has been entirely rewritten; some portions no longer important in theory and practice have been eliminated and a considerable amount of new matter added. The frontispiece is the first published photograph of a transatlantic wireless message, made by an Einthoven galvanometer, actuated by the detector current. It is noted that the longest distance for a wireless message was reached in 1910, receiving messages at Buenos Aires from Clifden, Ireland and Glace Bay in Nova Scotia.—W.P.C.

Institution of Electrical Engineers. List of Officers and Members, corrected to August 31, 1911. London, 1911. (Exchange.)

Iowa Electrical Association. Proceedings of the 11th Annual Convention. N.p. 1911. (Gift of Iowa Electrical Association.)

Kansas Gas, Water, Electric Light and Street Railway Association. Official Convention Proceedings 1911. Independence, Kan., 1911. (Gift of Kansas Gas, Water, Electric Light and Street Railway Association.)

New Orleans Sewerage and Water Board. Semi-annual Report. 22d–23d, 1910–11. New Orleans, 1910–11. (Gift of Sewerage and Water Board.)

New York (City) Board of Water Supply. Annual Report 5th, 1910. New York City, 1910. (Gift of Board of Water Supply.)

Peoria Water Works Company's decision on Electrolysis. By William Plattner. N.p. n.d. (Gift of author)

Propagation of Electric Currents in telephone and telegraph conductors. By J. A. Fleming. New York, Van Nostrand Co., 1911. (Gift of Publishers.) Price, $3.00.

Professor Fleming occupies the chair of Electrical Engineering in the University of London, and this volume is an amplification of the notes prepared for two courses of post-graduate lectures given to telegraphic and telephone engineers.

It has been the author's endeavor to simplify as far as possible the mathematical treatment of the subject, to fit the book for a text book for practical men; with this in mind he has furnished a mathematical introduction. The author acknowledges great indebtedness to Professor Kennelly, ex-President of American Institute of Electrical Engineers.—W.P.C.

Rugby Engineering Society. Proceedings Vol. III. Rugby, 1905. (Exchange.)

Short Course in the Testing of Electrical Machinery for non-electrical Students. By J. H. Morecroft and F. W. Hehre. New York, D. Van Nostrand Co., 1911. (Gift of Publishers.) Price, $1.50 net.

The authors are members of the faculty of Columbia University, and this work is designed for use with students who do not have the courses in the theory of electrical machinery which are required of electrical students.—W.P.C.

Spencer, Samuel. In memoriam. Exercises at the unveiling of the monument erected by the employees of the Southern Railway Company May 21, 1910. N.p. 1910. (Gift of General Committee of Southern Railway Employees.)

Theory and Practice of Technical Writing. By S. C. Earle. New York, Macmillan Co., 1911. (Gift of Publishers.) Price, $1.25 net.

A careful study of this work by technical men should be of benefit. It is eminently practical.

Digitized by Google

The chapters on "Addressing General Readers" and "Addressing Specialists" are particularly clear and convincing.

The appendix gives concrete examples in large number.—W.P.C.

Western Railway Club. Proceedings, Vol. 19, 1906–07. Chicago, 1907. (Gift of Western Railway Club.)

Western Union Telegraph Company. Annual Report of the President to the Stockholders. 1911. New York, 1911. (Gift of company.)

Gift of Bion J. Arnold

Detailed Exhibits of the Physical Property and Intangible Values of the Calumet Electric Street Railway Company. Accompanying the valuation report, March, 1908. Chicago, 1908.

Detailed Exhibits of the Complete Physical Properties and Intangible Values of the Southern Street Railway Company. Accompanying the Valuation Report December, 1908. Chicago, 1908.

Detailed Exhibits of the Physical Property and Intangible Values of the South Chicago City Railway Company. Accompanying Report submitted to the Committee on Local Transportation. March, 1908. Chicago, 1908.

Detailed Exhibits of the Tangible Property of the Chicago City Railway Company. Accompanying the Valuation Report. December, 1906. Chicago, 1906.

Detailed Exhibits of the Tangible Property of the Street Railway System in the possession of and operated by the receivers of the Chicago Union Traction Company. Accompanying Valuation Report, December, 1906. Chicago, 1906.

Recommendations and general plans for a Comprehensive Passenger Subway System for the City of Chicago, January, 1911. By B. J. Arnold. Chicago, 1911.

Report of the Board of Supervising Engineers Chicago Traction 1st–2d, 1908–09. Chicago, 1908–9.

Report of the Physical Properties and Intangible Values of the Calument Electric Street Railway Company and the South Chicago City Railway Company. By Traction Valuation Commission. March, 1908. Chicago, 1908.

Report on the Physical Property and Intangible Value of the Southern Street Railway Company. By Traction Valuation Commission, December, 1908. Chicago, 1908.

Report on the Engineering and Operating Features of the Chicago Transportation Problem with maps. By B. J. Arnold. New York, 1905.

Report on the Pittsburgh Transportation Problem. By B. J. Arnold, Pittsburgh, 1910.

Report on the Traction Improvement and Development within the Providence District to the Joint Committee on Railroad Franchises. By B. J. Arnold. Providence, 1911.

Report on the Values of the Properties of the Chicago Consolidated Traction Company inside the City limits By Traction Valuation Commission. August, 1910. Chicago, 1910.

Trade Catalogues

Crocker-Wheeler Co., Ampere, N. J. Bull. No. 134—Small direct current generating sets. 2 pp.

——Bull. No. 136—Electric hoisting machinery. 7 pp.

——Bull. No. 143—Engine type alternating current generators. 11 pp.

Cutter Co., Phila., Pa. Handbook of the I-T-E circuit breaker. 266 pp.

General Electric Co., Schenectady, N. Y. Bull. No. 4857—Switchboards and high tension relays for alternating current and direct current. 31 pp.

——Bull. No. 4859—Synchronous condensers. 16 pp.

——Bull. No. 4871—Mercury arc rectifiers. 16 pp.

——Bull. No. 4873—Control apparatus for steel mills. 26 pp.

——Bull. No. 4876—Small plant direct current switchboards. 20 pp.

Digitized by Google

General Electric Co., Shenectady, N.N. Bull. No. 4878—Cloth pinions. 6 pp.
——Bull. No. 4879—Direct current instruments types D-7 and D-8. 12 pp.
——Bull. No. 4882—Enclosed flame arc lamps. 4 pp.
——Bull. No. 4883—Curtis steam-turbine-generators. 47 pp.
——Bull. No. 4884—The lighting of iron and steel works. 40 pp.

Leeds & Northrup Co., Phila., Pa. Resistance boxes and Wheatstone bridges. 31 pp.
——Alternating current-direct current comparator. 12 pp.
——Electro-Dynamometers. 15 pp.

Siemens Bros. Works, Stafford, England Electricity in textile factories. 16 pp.
——New Electric generating station at the Northampton Polytech. Institute, London. 28 pp.
——Siemens fire alarm system. 28 pp.
——Fluid primary cells and batteries. 55 pp.
——Switchboard instruments. 116 pp.

Siemens & Halske, Berlin, Germany. Ships telegraph and signaling apparatus. 54 pp.
——Sterilization of drinking water by means of ozone. 15 pp.
——Water meters. 27 pp.
——Exposition, Berlin, 1908. 112 pp.

Siemens-Schucker & Werke, Berlin. Electric driven rolling mills. 18 pp.
——Electrically operated hoisting engines. 66 pp.
——Motor driven drills. 14 pp.
——Turbo-generators. 89 pp.
——Rock drills. 16 pp.
——Electrical operated switches and signals. 100 pp.
——Switch gear installations. 63 pp.
——Catalogue of Turin exhibition, 1911. 160 pp.
——Vacuum cleaning apparatus. 37 pp.
——Electric measuring instruments. 27 pp.
——Electric plant at Friedrichshall potassium works. 26 pp.
——Electricity and agriculture. 56 pp.
——Electric driven pumps for water works. 27 pp.
——Direct current turbo-generators. 28 pp.

United States Electric Co., New York. Bull. No. 501—Gill selectors for telephone train despatching. 20 pp.
——Bull. No. 701—Some preventable accidents on railways. 6 pp.

Wagner Electric Mfg. Co., St. Louis, Mo. Bull. No. 94—Unity power-factor, single phase motors. 11 pp.

Westinghouse Electric & Mfg. Co., East Pittsburg, Pa. Bull. No. 1028—Rotary converters. 23 pp.
——Bull. No. 1190—Engine driven a.c. generators. 11 pp.

Digitized by Google

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL. DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **ACTING SECRETARY.**

GEORGE A. HAMILTON. F. L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH WAINWRIGHT POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

HORACE FIELD PARSHALL,
Salisbury House, London Wall, E. C., London.

L.A. HERDT, McGill University, Montreal, Que.

WILLIAM G. T. GOODMAN,
Adelaide, South Australia.

ROBERT JULIAN SCOTT,
Christ Church, New Zealand.

HENRY GRAFTIO, St. Petersburg, Russia.

Digitized by Google

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
F. L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
JOHN PRICE JACKSON, State College, Pa.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

STANDARDS COMMITTEE.

ARTHUR E. KENNELLY, Chairman,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Secretary,
Harvard University, Cambridge, Mass.
FREDERICK BEDELL, Ithaca, N. Y.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
BENJAMIN G. LAMME, Pittsburgh, Pa.
WILBUR L. MERRILL, Schenectady, N. Y.
HAROLD PENDER, Boston, Mass.
WILLIAM H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburgh, Pa.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
J. FRANKLIN STEVENS, Philadelphia, Pa.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
FRED S. HUNTING, Fort Wayne, Ind.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES.

PUBLIC POLICY COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
HAROLD W. BUCK, New York.
JOHN J. CARTY, New York.
JOHN H. FINNEY, Washington, D. C.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman, 165 Broadway, New York.
EDWIN BRITTON KATTE, Vice-Chairman, New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

JOHN PRICE JACKSON, Chairman, State College, Pa.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
RALPH D MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman, General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, New York.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman, 139 Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman, 600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman, Allis-Chalmers Co., Milwaukee, Wis
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio
ROBERT BELDEN TREAT, Ampere, N. J.
R. TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman, 43 Exchange Place, New York.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman, 29 West 39th St., New York.
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman, 52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

Digitized by Google

SPECIAL COMMITTEES—*Continued.*

MEMBERSHIP COMMITTEE.

C. E. SCRIBNER, Chairman, 463 West Street, New York.
S. B. CHARTERS, San Francisco, Cal.
HENRY FLOY, New York.
GEORGE W. LAMKE, St. Louis, Mo.
A. A. MILLER, Seattle, Wash.
N. J. NEALL, Boston, Mass.
K. C. RANDALL, Pittsburgh, Pa.
DAVID B. RUSHMORE, Schenectady, N. Y.
A. M. SCHOEN, Atlanta, Ga.
H. CLYDE SNOOK, Philadelphia, Pa.
H. B. STABLER, Washington, D. C.
J. G. WRAY, Chicago, Ill.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman, 2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President, 90 West St., New York.
ARTHUR E. KENNELLY, Secretary, Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Cambridge, Mass.
LOUIS BELL, Boston, Mass.
JOHN J. CARTY, New York.
GANO DUNN (ex-officio), New York.
CARL HERING, Philadelphia, Pa.
JOHN W. HOWELL, Newark, N. J.
JOHN W. LIEB, Jr., New York.
RALPH D. MERSHON, New York.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
SAMUEL W. STRATTON, Washington, D. C.

CODE OF ETHICS COMMITTEE.

GEORGE FRANCIS SEVER, Chairman, 13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.

FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913.

COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.

WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.

LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, New York.

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.

GANO DUNN, President, Ampere, N. J.
F. L. HUTCHINSON, Acting Secretary.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New York.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, Pittsburgh, Pa.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.
ELIHU THOMSON, Swampscott, Mass

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

EDWARD B. ROSA, Washington, D. C.
J. B. WHITEHEAD, Baltimore, Md.

Digitized by Google

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta.....Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston.....Feb. 13, '03	William L. Hooper	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago.....1893	J. G. Wray.	
Cleveland.....Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor. Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.....Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca.....Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.....May 19, '08	O. H. Ensign.	E R Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison.....Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn.....Aug. 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico.....Dec. 13, '07	E. Leonarz.	
Milwaukee.....Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.....Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg.....Oct. 13, '02	K. C. Randall.	E L Farrar, G. E. Co , Oliver Bldg , Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass
Portland, Ore.....May 18, '09	F. D. Weber.	H. R. Wakeman, 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. B. Charters.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis.....Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo.....June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O
Toronto.....Sept. 30, '03	A. L. Mudge.	Vale tine Boyl, 212 King St , West, Toronto, Ont.
Urbana.....Nov. 25, '02	E. H. Waldo.	F G. Willson, University of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	F. D. Nims.	E M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington D. C.

Total, 27.

Digitized by Google

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L R Hulse, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio
Cincinnati, Univ. of..Apr. 10, '08		
Colorado State Agricultural College.....Feb. 11, '10	D. E. Byerley.	A A Catlin, 626 So Meldrum St., Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B. F Hillebrandt	W. C. Lane, Kansas State Agric. College, Manhattan
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, Kansas University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of.....Oct. 14, '10	W. H Jac le.	J. H Gaiser, 341 Harrison Ave., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute. .....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of .....Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo
Montana State Col...May 21, '07	J. Glen Luther	J. A .Thaler, Montana State College, Bozeman, Mont
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L, W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11		
Oregon State Agr. Col Mar. 24, '08	H Belknap.	W. R. Varner, Oregon St. Agric. College, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.....Jan. 26. '03	C. F. Harding.	A. L. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.....Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Polv. Institute, Troy, N. Y.
Rose Polytechnic Inst.Nov. 10, '11		
Stanford Univ.....Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.....Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of..... Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.....Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	O Krupp, Cal 65 North Bend St., Burlington, Vt.
Wash., State Coll. of..Dec. 13, '07	M K. Akers	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L Cheney.	P. S. Stevens, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.
Yale University.....Oct. 13, '11		

Total, 39.

Digitized by Google

CONTENTS OF SECTION II

Papers, Discussions and Reports

Magnetic Properties of Iron at Frequencies up to 200,000 Cycles. By E. F. Alexanderson, New York, November 10, 1911 - - - 2465

Tables of Hyperbolic Functions in Reference to Long Alternating-Current Transmission Lines. By A. E. Kennelly - - - - 2481

Central Station Generation of Power at Mining Centers. By J. V. Hunter, Fort Wayne, Ind., February 2, 1911 - - - - - 2493

Water Power Development - - - - - - 2503

Methods of Varying the Speed of Alternating Current Motors. By Gus A. Maier, New York, December 8, 1911 - - - - - 2511

Discussion on " Transmission Systems of the Western Power Co.," " The Southern Power Co.," " The Great Falls Power Co.," and " The Southern Colorado Power Co." Chicago, June 29, 1911 - - 2541

Discussion on " A Theory of Commutation and its Application to Interpole Machines, New York, October 13, 1911 - - - - 2550

Digitized by Google

Digitized by Google

A paper presented at the 265th Meeting of the American Institute of Electrical Engineers, New York, November 10, 1911.

Copyright, 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

MAGNETIC PROPERTIES OF IRON AT FREQUENCIES UP TO 200,000 CYCLES

BY E. F. ALEXANDERSON

The measurements of magnetization, core loss and skin effect of iron at high frequencies described in the following were undertaken partly in order to get data for predetermining the core loss and magnetic densities in high frequency alternators and partly in order to investigate the possible usefulness of iron for transformer construction at high frequencies.

Description of Apparatus

The generator used for producing 200,000 cycles is substantially of the same type as the 100,000-cycle alternator described by the author in a paper before this Institute in June, 1909. The 200,000-cycle alternator was designed primarily for the purpose of wireless telegraph and telephone service, particularly in connection with small antennæ used for transmission over moderate distances, where the natural frequency is higher than it is in high antennæ intended for long distance work. The output that can be obtained from a generator of a certain physical size decreases with the frequency or, *vice versa*, increases with lower frequencies, which is a fortunate circumstance inasmuch as the power needed for short distance transmission in relatively small, whereas, long distances require a greater amount of power and a lower frequency.

In the design of the alternator for 200,000 cycles some new difficulties were encountered. The size of slot used in the 100,000-cycle alternator is almost as small as it is practicable to use, if an adequate insulation is to be provided for a normal operating

Digitized by Google

potential of 110 volts and a high potential test of 750 volts. It was found possible to increase the number of slots from 600 to 800, retaining the same insulation, but beyond that it seemed that any increase in frequency must be obtained by an increase in speed. It appeared that the factor of safety of the material would allow a certain increase of speed, but there was another consideration which made the increase of speed almost prohibitive; the air friction. From measurements made on the 100,000-cycle alternator the law for the variation of the air friction with the speed has been determined, and it was found by plotting the results on a logarithmic scale that all the measured points within the whole range of speed where measurements could be made, fall on a straight line, indicating that the air friction is an exact function of the 2.7th power of the speed. The air friction of a 12-in. (31 cm.) disk at 20,000 rev. per min. is 5 kw. and hence a general formula is found for the air friction.

On a 12-in. disk;

$$\text{Air friction in kw.} = 0.76 \left(\frac{\text{rev. per min.}}{10000} \right)^{2.7}$$

Hence it was found that the speed needed for 200,000 cycles on the above assumption would require a power to be dissipated in air friction of 15 kw. which would be excessive particularly from the point of view of heating.

The 200,000-cycle alternator which has been developed has 800 slots but the machine runs at the same speed as the 100,000-cycle alternator, 20,000 rev. per min. The winding has one conductor per slot, insulated in the same way as the 100,000-cycle machine but the winding is of a special type so that 800 slots give the equivalent effect of 1200 poles. It generates 90 volts at no load.

System for Measurement

Inasmuch as the principal object of this test was to ascertain the core loss in the iron, it was necessary to find a way of making wattmeter measurements. The ordinary hot wire instruments have been found very reliable for measuring amperes and volts at high frequencies but a wattmeter for such frequencies does not exist. However, it might be possible to construct such an instrument applying the $a^2 - b^2$ principle to the hot wire meter. For these core loss measurements another method was adopted

Digitized by Google

which required no special instruments. The principle of the method is the following:

A compound circuit is formed of the sample coil, a bank of condensers, and a variable inductance. The relation of the capacity to the inductance is varied until the volt-amperes input through the combination becomes a minimum for a constant value of current in the sample coil. The minimum input indicates the changing point from leading to lagging current of the combination and consequently the input represents the watts consumed by the group. The iron core is then removed and the same measurements of minimum input is made with the remaining air circuit. This second measurement represents the loss in all the auxiliary apparatus and wiring, and the difference between the two measurements is the watts core loss in the iron sample.

In following out this principle it must be observed that any presence of higher harmonics in the measured circuit might give a certain amount of wattless current even at the point of minimum input and any such disturbance must be eliminated. For this purpose the alternator was connected in series with a variable condenser which was in every case adjusted so as to give maximum current output for any given field excitation. In this way the harmonics were eliminated by tuning, so that a comparatively pure sine wave was delivered to the test circuit.

In arranging the test circuit there was a choice between connecting the condensers in multiple to the sample coil and tuning for minimum current input or connecting the condensers in series with the sample and tuning for minimum voltage input. Out of these two alternatives the second proved to be more convenient and was used throughout. The accuracy of the method was ascertained by substituting a known resistance in the place of the sample coil and checking the measured input to the same with the calculated $I^2 R$ loss. The results agreed within the errors of measurement. The arrangement of the test circuit employed is shown in Fig. 1. The sample coil is connected in series with a bank of condensers of one microfarad each, arranged in series, and a variable inductance consisting of a fine insulated wire about 1.5 meters along which was wound or unwound on a cylinder of wood about two cm. in diameter. This type of variable inductance was preferred to the one of the ordinary laboratory type where a blank wire is gradually rolled

Digitized by Google

from an insulated to a conducting cylinder. It is of importance that no change be made in the losses in the auxiliary apparatus, because the core loss in the sample is determined by subtracting the losses in the apparatus from the total losses in the combination. The current was measured by a three-ampere hot wire meter with all the current flowing through the hot wire and the voltage was measured by a hot wire voltmeter with a full scale deflection corresponding to 0.23 amperes. Inasmuch as the series resistances of the voltmeter were originally made for ordinary frequencies it might be questioned whether they are sufficiently non-inductive for accurate readings on high frequencies. The tests made to ascertain this point indicate however that there is no measurable error even at 200,000 cycles. In the first place the readings of the voltmeter are proportional to the speed of the alternator over the whole range of speed in which the machine can be operated. For additional assurance it was tried to eliminate any possible inductance in the voltmeter by connecting it in series with a variable condenser, and it was found that the maximum reading was obtained without the condenser and that the readings decreased first slowly and then rapidly when the impedance of the condenser was increased.

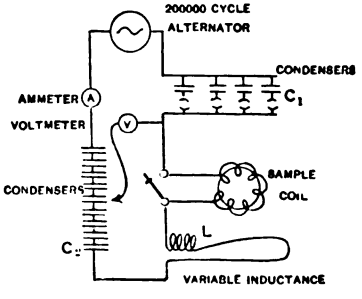


FIG. 1.—Arrangements for measurements

The sample coil consisted of a ring 2 in. (5.1 cm.) in diameter made up of 10 turns of a soft iron strip 0.003 in. thick and 0.75 in. wide (0.0076×1.9 cm.). The layers of the strip were separated by thin paper. The winding was made of 0.016 silk covered wire with two wires in multiple and 20 turns in series.

The test comprised two sets of measurements:

Skin effect measurements;

Core loss measurements.

This skin effect measurements consisted in determining the apparent permeability of the iron at various frequencies and densities by observing the volts and amperes at the terminals of the sample coil. The complete sets of observations at various frequencies are given in Table I.

Digitized by Google

TABLE I
SKIN EFFECT MEASUREMENTS

Frequency	Amperes	Volts	*Bmax* lines per cm²	Effective ampere turns per cm.
40,000	1.8	8.2	1550	2.25
	1.64	7.4	1440	2.05
	1.48	6.7	1300	1.85
	1.28	5.2	1010	1.6
60,000	2.02	12.8	1650	2.53
	1.88	11.3	1460	2.35
	1.74	10.2	1320	2.18
	1.33	7.2	930	1.66
80,000	2.37	18.4	1780	2.97
	2.14	15.3	1480	2.68
	1.82	12.3	1190	2.28
	1.48	9.2	890	1.85
100,000	2.46	20.4	1580	3.08
	2.06	16.2	1260	2.58
	1.64	11.5	890	2.05
	1.27	8.4	650	1.59
120,000	2.38	21.8	1410	2.98
	2.14	18.0	1160	2.68
	1.83	14.3	925	2.29
	1.38	10.2	660	1.73
	1.6	11.9	770	2.0
140,000	2.29	22.0	1220	2.86
	1.94	17.3	960	2.43
	1.69	13.7	760	2.11
160,000	2.26	22.6	1090	2.83
	2.00	19.0	920	2.5
	1.69	14.7	710	2.11
	1.37	11.3	550	1.71
180,000	2.32	24.8	1070	2.9
	2.20	22.8	885	2.75
	1.91	18.4	790	2.39
	1.50	13.5	580	1.88
	1.25	10.5	450	1.56
200,000	2.34	26.1	1010	2.93
	2.04	21.3	820	2.55
	1.67	16.4	635	2.09
	1.27	11.5	446	1.59

The method of procedure during the core loss measurements was as follows:

The alternator was held at constant speed and the outside condenser C_1 was tuned so as to give maximum current for that particular frequency. The voltmeter connection was then

Digitized by Google

moved along the bank of condensers C_2 until the point was found which gave approximately minimum volt reading. The variable inductance was then wound or unwound until the exact minimum point was found. With this adjustment of the circuit, a continuous series of readings was taken by varying the field strength of the alternator and noting the volts and amperes input to the test circuit. The sample coil was then short circuited and another tuning of the auxiliary circuit undertaken leaving the voltmeter connection in the same place but increasing the variable inductance by winding up the wire until the minimum volt reading was found. The same procedure was repeated at each of the various frequencies from 40,000 to 200,000 cycles. The complete data as obtained from tests is given in Table II.

TABLE II
CORE LOSS MEASUREMENTS

Frequency	Amperes	Minimum volt total	Minimum volt auxiliaries	Minimum volt coil	Effective ampere turns per cm.
40,000	1.96	8.4	0.53	7.9	2.45
	1.87	7.4	0.48	6.9	2.34
	1.77	7.0	0.43	6.6	2.21
	1.52	5.1	0.32	4.8	1.9
	1.23	3.9	0.20	3.7	1.54
60,000	2.08	10.5	0.8	9.7	2.6
	1.92	9.2	0.68	8.5	2.4
	1.78	8.2	0.59	7.6	2.23
	1.63	7.2	0.49	6.7	2.04
	1.31	5.1	0.32	4.8	1.64
	1.06	4.1	0.21	3.9	1.33
80,000	2.32	15.2	1.2	14.0	2.9
	2.18	13.7	1.06	12.6	2.73
	2.05	12.1	0.94	11.2	2.56
	1.80	9.5	0.72	8.8	2.25
	1.60	8.2	0.57	7.6	2.0
	1.33	6.5	0.4	6.1	1.66
	1.08	4.9	0.26	4.3	1.35
100,000	2.29	16.5	1.68	14.8	2.88
	2.02	13.4	1.31	12.1	2.53
	1.76	11.0	1.0	10.0	2.20
	1.61	9.3	0.83	8.5	2.01
	1.33	7.4	0.57	6.8	1.66
	1.06	5.3	0.36	4.9	1.32
120,000	2.44	19.0	1.54	17.5	3.05
	2.26	17.1	1.3	15.8	2.82
	1.94	13.7	0.97	12.7	2.43
	1.65	10.5	0.70	9.8	2.06
	1.39	8.4	0.50	7.9	1.74
	1.12	6.6	0.32	6.3	1.4

Digitized by Google

TABLE II—CONTINUED

Frequency	Amperes	Minimum volt total	Minimum volt auxiliaries	Minimum volt coil	Effective ampere turns per cm.
140,000	2.24	17.8	1.46	16.3	2.8
	2.01	14.9	1.18	13.7	2.52
	1.67	11.4	0.81	10.6	2.09
	1.34	9.0	0.52	8.5	1.68
	1.08	7.0	0.34	6.7	1.35
	1.79	12.7	0.96	11.7	2.24
	2.20	17.6	1.42	16.2	2.75
160,000	2.75	26.9	3.1	23.8	3.44
	2.67	26.5	2.92	23.6	3.34
	2.40	22.5	2.37	20.1	3.0
	2.16	19.0	1.92	17.1	2.7
	1.89	15.3	1.46	13.8	2.36
	1.53	11.5	0.96	10.5	1.91
	1.26	9.0	0.65	8.4	1.58
	1.12	7.7	0.51	7.2	1.4
180,000	2.38	22.8	2.62	20.2	2.98
	2.50	24.8	2.9	21.9	3.13
	2.25	21.4	2.34	19.1	2.81
	1.95	17.4	1.76	15.6	2.44
	1.68	13.7	1.3	12.4	2.10
	1.32	10.1	0.81	9.3	1.65
	1.04	7.6	0.5	7.1	1.30
200,000	2.32	23.1	2.4	20.7	2.9
	1.93	17.6	1.66	16.0	2.41
	1.75	15.1	1.36	13.7	2.19
	1.52	12.6	1.03	11.6	1.9
	1.19	9.2	0.63	8.6	1.49
	0.98	7.4	0.44	7.0	1.22

For the sake of completing the data the same sample coil was tested at 1740 cycles and at 60 cycles in order to ascertain the permeability and core loss at lower frequencies. In these two sets of measurements a dynamometer was used for determining the core loss.

Although the apparatus described above for measurements at high frequencies was convenient to use and worked with all the accuracy that could be desired, it was found rather difficult in the beginning to get consistent measurements that could be reproduced. The quantity that was difficult to control was the actual properties of the iron due to the rapid changes in temperature. The skin effect or apparent permeability as well as the core loss is a function of the specific resistance, which on the other hand varies with the temperature. In order to maintain constant temperature the sample core was immersed in oil, however, the heat radiation was not as rapid as might be desired

Digitized by Google

because the coil, in order to give a closed magnetic circuit was solidly wrapped in tape. At the highest densities and the highest frequencies that were used the heating of the iron was so rapid that the apparent permeability could be observed to increase about 20 per cent after the circuit was closed, the whole change taking place in about half a minute.

The following corrections of the measured results have been considered but it was concluded that none was of a magnitude that would be worth taking into account.

The inductance of the air circuit surrounding the winding of the coil.

Resistance of the winding.

Error due to current absorbed by the voltmeter.

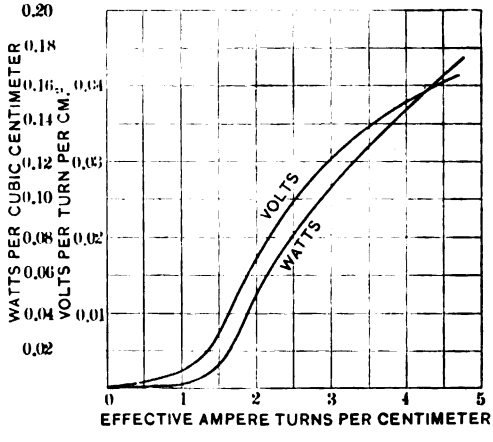


FIG. 2.--Saturation and core loss at 60 cycles

In order to ascertain the inductance of the air circuit of the coil winding an identical sample coil was made up with a paper core instead of the iron core. The inductance was, however, too low to be measured. Similarly it was found that the resistance could be neglected. The correction for the voltmeter current might be considered appreciable being about 4 per cent, however, considering the possible variations of several times this amount due to heating all efforts were bent to produce measurements which are consistent with each other rather than to correct the absolute quantities. The sets of readings given in Tables I and II are the results after several less successful attempts. The method finally adopted in taking the readings

Digitized by Google

was to complete all the tuning, then let the coil cool and take the readings rapidly, closing the circuit only for a moment at a time.

The data represented by curves in Fig. 2 to Fig. 11, inclusive, are obtained from the test results given in Tables I and II in combination with some other tests made with a 100,000 cycle alternator in order to reach the intermediate frequencies.

Figs. 4 to 7 inclusive, give the data on magnetizing current and skin effect, whereas Figs. 8 to 11 inclusive, give the data on core loss. Fig. 5 gives the magnetization of the iron in the same form as ordinary alternating current saturation curves, one curve

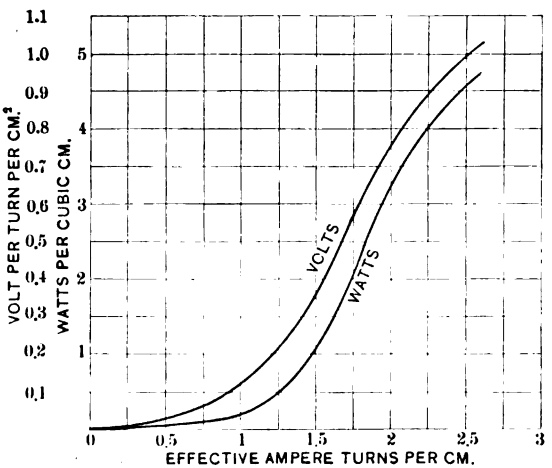


FIG. 3.—Saturation and core loss at 1,740 cycles

being drawn for each frequency. The curves in Fig. 6 show the decrease of the apparent magnetic densities with increasing frequency; in other words, the skin effect. Fig. 7 gives the magnetizing current in a form which is most useful for the purpose of design. Each curve represents a constant value of effective volts induced by a cross section of one square centimeter of the core. The curves show that, in spite of the skin effect, the magnetizing current needed to produce the same induced voltage decreases continually with increasing frequency. Fig. 11 gives the core loss in a similar form, each curve representing a constant value of volts produced per square centimeter of the core. The core loss, like the magnetizing current, decreases with increasing frequency.

Digitized by Google

Conclusions

As a conclusion from these tests it may be stated that the opinion held quite extensively that iron does not respond to high frequencies is entirely without foundation. The iron not only responds but it seems to have the same permeability at 200,000 cycles as at 60 cycles. The apparent permeability of the iron in

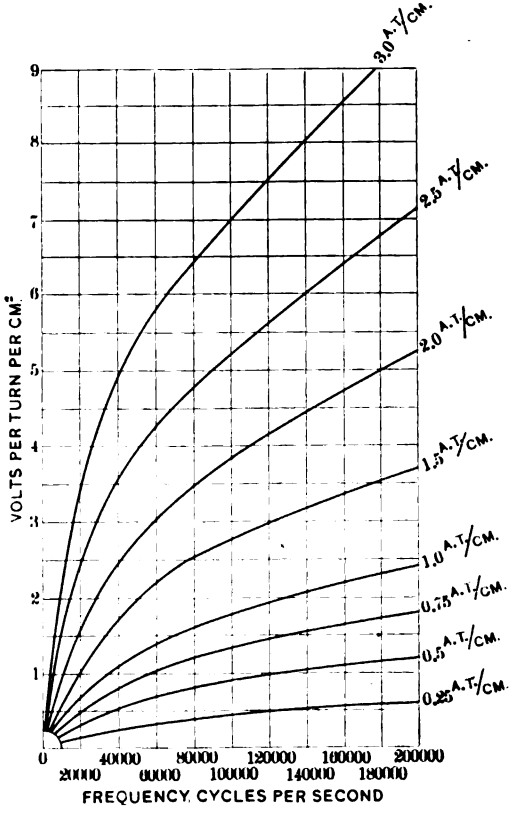


Fig. 4.—Induced volts at constant ampere turns and varying frequency

the sample which was tested is only about one-tenth as great at the high frequencies as at the low frequencies but the decrease of the apparent permeability is substantially in agreement with the change that would be expected from purely theoretical considerations due to the skin effect, which indicates that the actual permeability has remained unchanged.

Digitized by Google

In order to apply Steinmetz's formula for skin effect:

$$\text{Penetration, } 1_p = \frac{3570}{\sqrt{\lambda}\,\mu f} \text{ *}$$

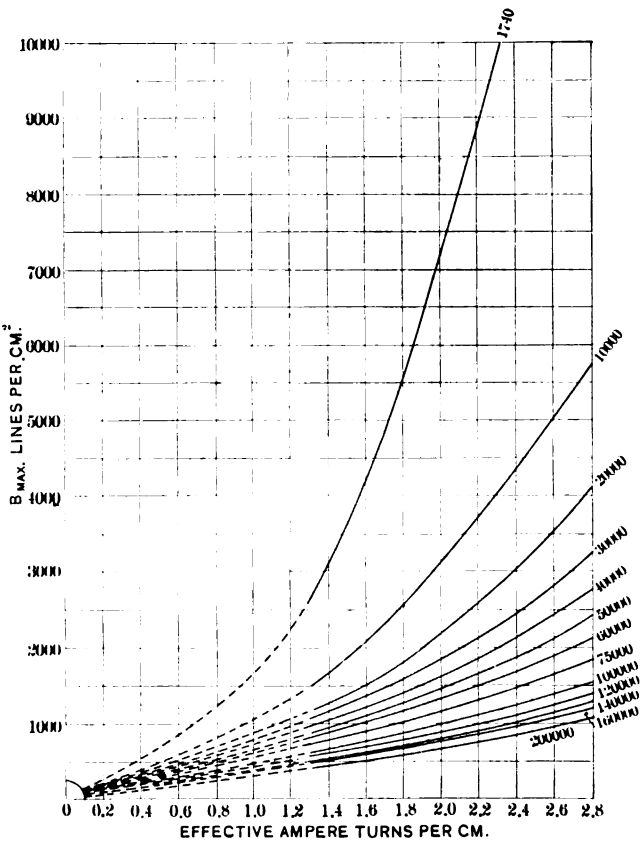


FIG. 5.—Alternating current saturation curves

The following constants may be used as average values for the sample

$$\text{Permeability, } \mu = 2{,}250$$

$$\text{Conductivity, } \lambda = 0.9 \times 10^5$$

*Transient Electric Phenomena and Oscillations.

Digitized by Google

Hence penetration at 200,000 cycles should be

$$l_p = 0.00056 \text{ cm.}$$

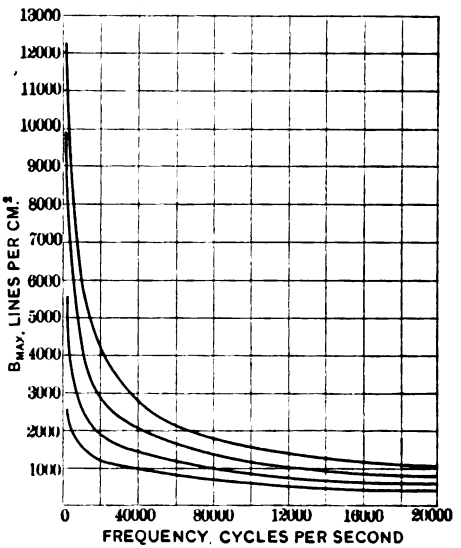


FIG. 6.—Apparent densities at constant ampere turns and varying frequency

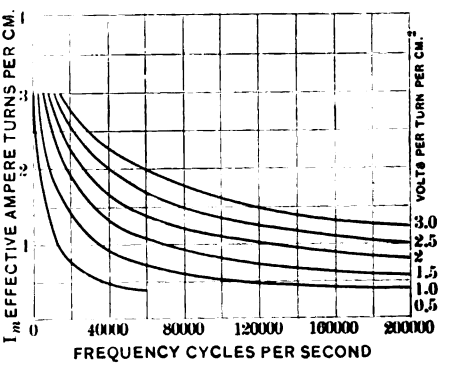


FIG. 7.—Magnetizing current at constant volts per turn and varying frequency

The data from the tests give

Average permeability at low frequency.....	2250
Average apparent permeability at 200,000 cycles....	180

Hence penetration $= 0.0076 \times \frac{1}{2} \times \frac{180}{2250} =$ ..... 0.003 cm.

Digitized by Google

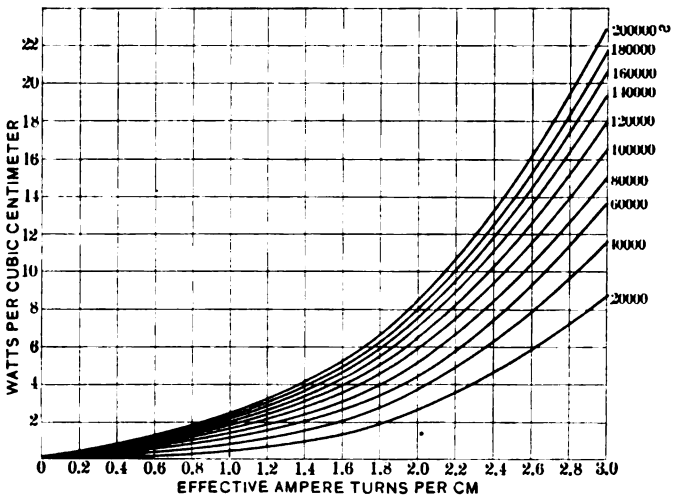


FIG. 8.—Core loss at constant frequencies and varying ampere turns

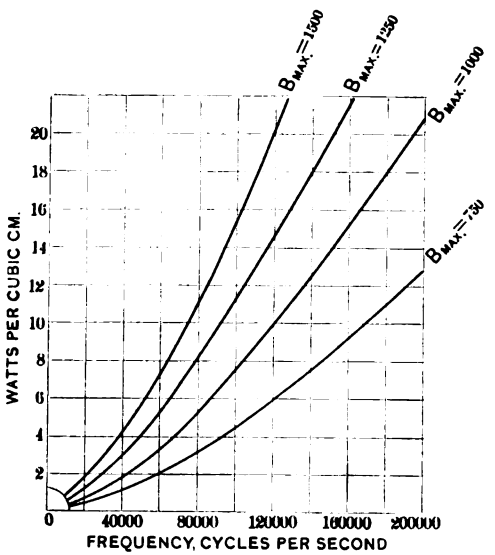


FIG 9 —Core loss at constant apparent densities and varying frequency

Digitized by Google

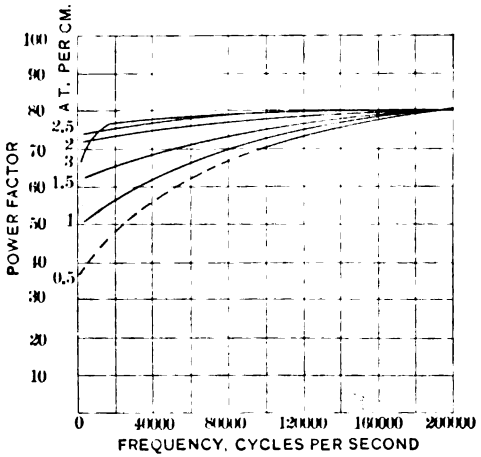


FIG. 10.—Power factor at varying frequency

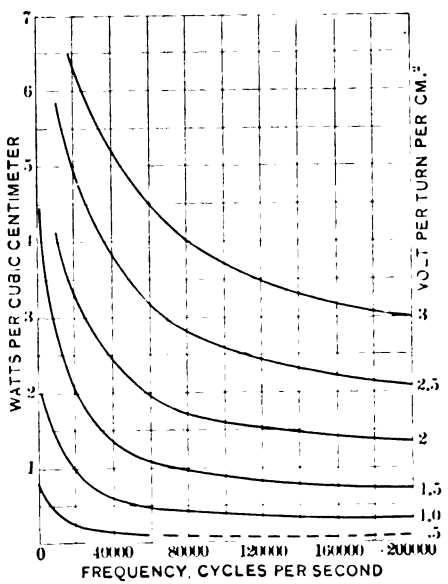


FIG. 11.—Core loss at constant volts per turn and varying frequency

Digitized by Google

The discrepancy between the measured and calculated values of the penetration is probably due to the fact that the coil has not a completely closed magnetic circuit, but depends upon the leakage from turn to turn of the laminations, whereby an additional skin effect is created.

The data on the magnetic properties of iron at high frequencies may be of more interest if it can be shown that iron may actually be useful in the construction of apparatus for such frequencies. Its usefulness may be claimed to be already demonstrated in as far as the construction of a 200,000 alternator would have been impossible without an iron armature. There is however, a generally accepted opinion that transformers for high frequencies cannot be made with iron core. On the other hand there is a well known rule that transformers for ordinary frequencies

TABLE III

DESIGNS OF FIVE-KW. TRANSFORMER AT VARIOUS FREQUENCIES

Frequency	60	1740	10000	500000	1000000	2000000
Dimension of core, cm	4.65	2.51	2.41	2.14	2.06	2.0
Weight, kg	19.5	3.05	2.7	1.9	1.7	1.5
Volts per turn / Per cm² of iron	0.04	0.47	0.56	0.92	1.08	1.22
Core loss	120	156	92	56	54	52
I^2R	450	70	62.4	44	39	35
Efficiency	90	96	97	98.1	98.2	98.3
Per cent magnetizing current	5	5.6	2.9	1.73	1.5	1.3

are lighter and more efficient at the higher frequencies. In order to examine the usefulness of iron for transformer design from the point of view of this rule a series of transformer designs have been made on the basis of the measurements of the skin effect and core loss. It might be expected that there would be found a turning point in the usefulness of iron, but actually it appears that the rule holds true at 200,000 cycles and probably a good deal higher.

The series of transformer designs shown in Table III is made on a purely theoretical basis so as to illustrate the magnetic properties of iron on a uniform plan. Considerations that would be involved in a practical design such as insulation and capacity between turns have been left out entirely. All the designs have the same proportions of core and winding space and the heating is figured uniformly on the basis of one watt per square inch

Digitized by Google

(0.156 watt per cm.^{2}) for radiation of the core loss from the surface of the iron. The insulation between laminations has been assumed to be one-half of the thickness of the sheet. The current density in the winding is assumed to be 3000 amperes per square inch (470 amperes per cm^2) the copper occupying one-third of the winding space. The calculations show that the 200,000-cycle transformer has an astonishingly low weight and is very efficient, whereas, the 60 cycle transformer built on the same proportions is too inefficient to be acceptable and although it weighs twelve times as much as the 200,000-cycle transformer it should weigh a good deal more in order to reach a reasonable efficiency. It should also be noted that the 200,000-cycle transformer, in spite of its skin effect, has a magnetizing current of only 1.3 per cent, whereas the magnetizing current would be about 40 per cent if the core was removed. These figures are not given in order to advocate the use of iron transformers to the exclusion of air core transformers for special purposes where such apparatus is used but are simply intended to show that high frequency transformers can be built with iron and would compare very favorably in weight and efficiency with transformers for ordinary frequencies.

Digitized by Google

A paper communicated to the American Institute of Electrical Engineers, by Dr. A. E. Kennelly.

Copyright 1911. By A. I. E. E.

(*Subject to final revision for the Transactions.*)

TABLES OF HYPERBOLIC FUNCTIONS IN REFERENCE TO LONG ALTERNATING-CURRENT TRANSMISSION LINES

BY A. E. KENNELLY

The formulas relating to the behavior of long alternating-current lines of uniform resistance, inductance, capacitance and leakance, operated in the steady state, are very simply expressed in terms of hyperbolic functions; but are very long and cumbersome if expressed, with equal precision, without those functions. The absence of suitable tables* of hyperbolic functions of complex variables has, however, stood in the way of the general use of hyperbolic formulas. A few tables of such functions, in terms of real and imaginary components, have been published; but these are not so convenient for engineering purposes as tables of vector variables, using polar coördinates.

* The following is a list of Tables of Complex Hyperbolic Functions thus far published:

1. "Hyperbolic Functions" by Dr. James McMahon, Chapter IV of "Higher Mathematics" by Merriman and Woodward, pp. 107–168. Sinh and cosh $(x+jy)$ to $x=1.5$, $y=1.5$. Wiley and Sons, New York, 1896.

2. "The Alternating-current Theory of Transmission Speed over Submarine Telegraph Cables," by A. E. Kennelly. *Proc. Int. El. Congress. St. Louis*, Sec. A, Vol. I, pp. 68–105, 1904. Table of sinh, cosh, tanh, cosech, sech, coth $\rho/45°$, up to $\rho=20$.

3. "The Distribution of Pressure and Current over Alternating-Current Circuits," by A. E. Kennelly, *Harvard Engineering Journal*, 1905–06. Tables of sinh, cosh, tanh, cosech, sech, coth $\rho/\underline{\delta}$ up to $\rho=1.5$ for five particular values of δ.

4. "Formulæ, Constants and Hyperbolic Functions for Transmission Line Problems," by W. E. Miller, *General Electric Review*, Schenectady, N. Y., May, 1910, Supplement. Sinh and cosh $(x+jy)$ up to $x=1$. $y=1$.

Digitized by Google

The accompanying tables have been computed by the writer for particular application to transmission-line problems. They extend up to 0.5 in modulus, by steps of 0.1, and from 60 deg. to 90 deg. inclusive, of argument, by steps of single degrees. The results are given to five significant digits of modulus, and to decimals of a degree, as far as the third decimal place, or to about 3.6 seconds of arc. The reasons for expressing circular angles in degrees and decimals of a degree, instead of in degrees, minutes, and seconds, were first—that the results are thereby

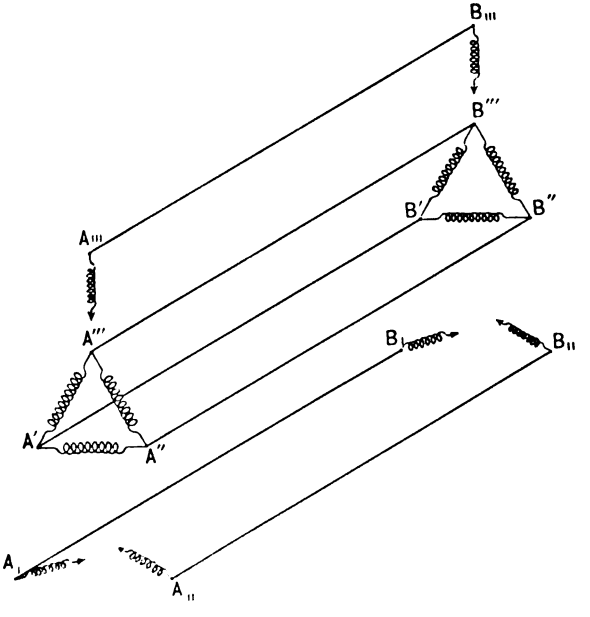


FIG. 1.—Analysis of a three-phase system into three component single-phase systems

more compactly expressed; second—that interpolations are simplified, and third—that reduction to French "grads" may be made if desired, merely by dividing with 0.9. The moduli results in the table, errors excepted, are correct up to the last digit, which is doubtful to the extent of unity. The circular angles resulting from the tables, errors excepted, are correct up to the last digit, which is doubtful to the extent of unity, representing 0.001 degree. Such a degree of precision in the tables is unnecessary for ordinary alternating-current engineering re-

Digitized by Google

quirements; but has been adopted because the tables are intended to form the nucleus of a subsequent and more extensive series, applicable to telephonic-circuit problems. The tables here offered suffice for the longest existing power-transmission lines, operated at fundamental frequencies. They do not purport to cover the behavior of such lines with higher harmonic frequencies.

Directions for the Use of the Tables with Power-Transmission Three-phase Lines

Let the three-phase line considered be uniform throughout, and free from intermediate loads. If there be a load applied to the system at a substation along the line, the line must be divided at the substation into two distinct uniform sections, and each must be treated separately.

Analyze the three-phase line system $A'B'$, $A''B''$, $A'''B'''$, into three separate single-phase lines, $A, B_,$, $A_,, B_,,$, $A_,,, B_,,,$, Fig. 1, in the usual way, each such single line carrying one third of the load, and being operated, at star voltage, with respect to its enveloping surface of zero-potential. This well known step enables us to consider one line only, say $A\,B$, operated as though single-phase, with its independent linear constants.

Find the total resistance R in the line $A\,B$ (ohms).

Find the total reactance $j\,X = j\,\mathcal{L}\,\omega$ in the line $A\,B$ (ohms);

where $\mathcal{L}$ is the wire inductance in henrys, and ω is the angular velocity $2\,\pi f$, in radians per second, f being the frequency of operation, in cycles per second.

Find the total leakance G in the line $A\,B$, if any (mhos).

Find the total susceptance $j\,B = j\,C\,\omega$ in the line $A\,B$, (mhos);

where C is the total wire capacitance to zero-potential surface, in farads.

Ordinarily, the leakance G is negligible, but it may be included for the sake of generality.

Proceed to find the total wire impedance $R + j\,X = Z/\beta_1$ ohms, where Z is the vector impedance at the angle β_1. The numerical value of Z may be called the *modulus*, and the value of β_1 the *argument*, of the plane vector impedance.

Also find the total wire admittance $G + j\,B = Y/\beta_2$ mhos, where Y is the vector admittance modulus, and β_2 the admittance argument.

Digitized by Google

Lay off a conductor, *A B*, Fig. 2, to represent the wire *A B* of the line by the well-known "split-condenser" method.* In the line *A B*, place an air-cored reactance coil of impedance *Z* ohms. At each end of the line, place a condenser of half the admittance *Y* mhos. Then the three-part artificial line *A B G G* will represent one wire of the line, except that it has its total dielectric admittance applied in two equal terminal lumps, instead of being applied in uniform distribution. The line *A B G G*, thus constituted, may be called the "***nominal Π***" of one wire of the line; because the nominal values of the wire's impedance and admittance are ascribed to it. A nominal *Π* artificial line is unable correctly to imitate the behavior of an actual transmission line-wire, owing to the lumpiness error, just

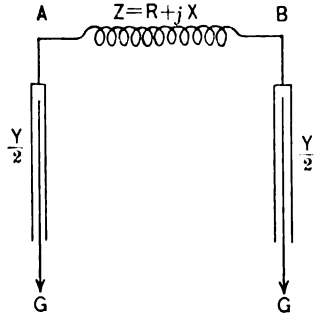


FIG. 2.—Nominal *Π* of one line wire *A B*

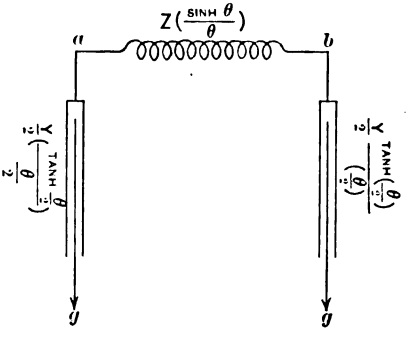


FIG. 3.—Equivalent *Π* of one line wire of angle *θ*

referred to; but it is readily possible so to modify the value of the impedance *Z* in the *architrave A B*, and also the value of the admittance *Y*/2 in each *pillar*, *A G* or *B G*, of the nominal *Π*, as will make the lumpiness error vanish, or will make the artificial line truly represent, at the terminals, the behavior of one line wire, taking distributed leakance and capacitance into account. Such a corrected artificial line may be called the "equivalent *Π*" of the line-wire†; because it then becomes externally equivalent

* See a paper on "Calculation of the High-tension Line." by P. H. Thomas, TRANSACTIONS A. I. E. E., Part I, Vol. XXVIII, June, 1909. pp. 641–686.

† The theory and demonstration of this proposition are given in "The Application of Hyperbolic Functions to Electrical Engineering Problems," by A. E. Kennelly. The University of London Press. Chapter III, p. 33.

Digitized by Google

to the same in every respect, during steady operation. The algebraic factors that must be applied to Z and $Y/2$, in order to convert the nominal Π into the equivalent Π, may be called the *correcting-factors* of the nominal Π.

The correcting-factor of the architrave impedance $A\,B$ is $\frac{\sinh\theta}{\theta}$, and the corresponding correcting-factor of each pillar admittance, $A\,G$ or $B\,G$, is $\frac{\tanh\frac{\theta}{2}}{\frac{\theta}{2}}$; where θ is the hyperbolic angle subtended by the line, in hyperbolic radians,* defined by the relation:

$$\theta = \sqrt{Z\,Y} \qquad \text{hyperbolic radians } \angle.$$

This hyperbolic angle will be a plane-vector quantity. Its modulus will not exceed 0.5, with transmission lines operated at ordinary frequencies, and its argument will lie between 60 deg. and 90 deg. The equivalent Π of a line-wire is represented diagrammatically at $a\,b\,g\,g$, Fig. 3.

Having, therefore, found the line-angle θ, enter Table IV, for the nearest given architrave correcting-factor, and Table V, for the nearest given pillar correcting-factor. In general, the corrected line-wire impedance, which becomes $Z\left(\frac{\sinh\theta}{\theta}\right)$, is slightly diminished in modulus, but slightly increased in argument. This ordinarily represents a slight reduction in conductor resistance, associated with a very small change in conductor reactance. That is, the $I^2\,R$ loss on a line wire is slightly reduced by correcting from the nominal Π to the equivalent Π; or, the distributed capacity in a line produces slightly less $I^2\,R$ loss, in actual operation, than if the line had its capacity applied in two equal terminal lumps. Again, Table V shows that the pillar correcting factor slightly increases the admittance modulus, but slightly diminishes the admittance argument; so that some $I^2\,R$ loss appears in the terminal condensers.

Having found the equivalent Π of each wire of the line as above, the behavior of the wire, under any assigned normal load, can be determined by known rules for simple alternating-current circuits.

*See TRANSACTIONS American Institute of Electrical Engineers, Part I, Vol. XVII, pp. 698, 702, June 29, 1909. Discussion on Thomas' paper.

Digitized by Google

Harmonic Frequencies. It has been assumed in the foregoing discussion that the e.m.f. existing at each end of the line possesses a purely sinusoidal wave-shape; or, in other words, contains the fundamental frequency only. If harmonic frequencies in the impressed e.m.f. have to be taken into account, the process must be repeated for each harmonic frequency in turn. That is, the impedance Z, admittance Y, and line angle $\theta = \sqrt{Z\,Y}$, must be found for each harmonic frequency, independently. The nominal and equivalent Πs of the line are then found for each such frequency. Under a given condition of load, the distribution of pressure and current is thus obtained for each frequency component, as though it acted alone. The resulting total distribution of pressure and current is then derived through the superposition of the various component distributions, by the process of* " crab-addition ", or equivalent methods. In general, the accompanying tables are not sufficiently extended in modulus to provide for cases of harmonics higher than of triple-frequency on very long lines; although they may cover cases of higher harmonics on shorter lines.

Single-Phase Circuits. The analysis of a single-phase line, with two conductors, differs only from that of a three-phase line already discussed, in applying half the circuit load and impressed e.m.f., to each of the two wires, considered as operated to zero-potential surface.

Interpolation between Tabular Values. In using the Tables, interpolation is required both for intermediate values of the modulus, and for intermediate values of the associated argument. Thus, in finding $\frac{\sinh \theta}{\theta}$, from Table IV, for the particular value of $\theta = 0.25/70.5$ deg., we require to find, first, the interpolated value $0.25/\overline{70}$ deg., which is $0.98174/0°.4$ (on the basis of simple proportion), and then to deduce the interpolated value for $0.25/70°.5$ by subtracting $0.00025/0.012$, (the mean difference for 0.5 deg. of argument), obtaining, as the result, $0.98149/0°.388$. It should be observed, however, that owing to the rate at which the tabular values are changing, and the relatively large steps of 0.1 in modulus, simple proportional interpolation cannot be relied upon for precision in the fifth

*" The Application of Hyperbolic Functions to Electrical Engineering Problems ", Chapter VII, p. 101.

Digitized by Google

digit. In other words, unless second differences are taken into account, which involves much labor, the interpolated values can only be relied on to four digits, with the last in some doubt. In general, a sufficiently good interpolation for most practical alternating-current engineering purposes can be made by direct inspection, at a corresponding sacrifice of attempted high precision.

TABLE I
HYPERBOLIC SINES

	0.1		0.2		0.3		0.4		0.5	
60°	0.099917	60°.082	0.19934	60°.331	0.29777	60°.746	0.39474	61°.330	0.48978	62°.085
61°	0.099912	61.081	0.19929	61.324	0.29764	61.731	0.39441	62.302	0.48916	63.042
62°	0.099907	62.079	0.19925	62.317	0.29751	62.715	0.39409	63.273	0.48855	63.998
63°	0.099902	63.077	0.19921	63.309	0.29738	63.698	0.39379	64.243	0.48795	64.950
64°	0.099897	64.075	0.19918	64.301	0.29725	64.680	0.39349	65.212	0.48738	65.900
65°	0.099893	65.073	0.19914	65.293	0.29712	65.661	0.39320	66.179	0.48681	66.848
66°	0.099889	66.071	0.19911	66.284	0.29700	66.641	0.39293	67.144	0.48627	67.794
67°	0.099885	67.069	0.19908	67.275	0.29689	67.621	0.39266	68.108	0.48575	68.738
68°	0.099881	68.066	0.19904	68.265	0.29678	68.599	0.39240	69.070	0.48523	69.679
69°	0.099877	69.064	0.19901	69.255	0.29667	69.577	0.39214	70.030	0.48473	70.617
70°	0.099873	70.062	0.19898	70.245	0.29657	70.555	0.39190	70.990	0.48426	71.554
71°	0.099869	71.059	0.19895	71.235	0.29647	71.532	0.39167	71.948	0.48380	72.489
72°	0.099865	72.057	0.19892	72.225	0.29637	72.508	0.39145	72.905	0.48338	73.422
73°	0.099861	73.054	0.19889	73.214	0.29628	73.483	0.39123	73.861	0.48296	74.354
74°	0.099858	74.051	0.19887	74.203	0.29620	74.458	0.39104	74.817	0.48257	75.284
75°	0.099855	75.048	0.19885	75.192	0.29612	75.432	0.39084	75.771	0.48220	76.212
76°	0.099852	76.045	0.19883	76.180	0.29604	76.406	0.39066	76.724	0.48184	77.138
77°	0.099850	77.042	0.19881	77.168	0.29596	77.379	0.39050	77.676	0.48152	78.062
78°	0.099847	78.039	0.19878	78.156	0.29590	78.351	0.39034	78.628	0.48123	78.986
79°	0.099845	79.036	0.19876	79.144	0.29584	79.322	0.39018	79.578	0.48095	79.909
80°	0.099843	80.033	0.19875	80.131	0.29578	80.294	0.39004	80.528	0.48067	80.830
81°	0.099841	81.030	0.19873	81.118	0.29573	81.266	0.38993	81.477	0.48044	81.750
82°	0.099839	82.026	0.19872	82.106	0.29569	82.238	0.38983	82.425	0.48023	82.669
83°	0.099838	83.023	0.19871	83.093	0.29566	83.209	0.38973	83.373	0.48004	83.587
84°	0.099837	84.020	0.19870	84.080	0.29563	84.180	0.38965	84.321	0.47987	84.505
85°	0.099836	85.017	0.19869	85.067	0.29561	85.150	0.38958	85.268	0.47972	85.422
86°	0.099835	86.014	0.19868	86.054	0.29559	86.120	0.38952	86.215	0.47960	86.338
87°	0.099834	87.011	0.19868	87.041	0.29557	87.090	0.38948	87.162	0.47952	87.254
88°	0.099833	88.008	0.19867	88.028	0.29555	88.060	0.38946	88.108	0.47947	88.170
89°	0.099832	89.004	0.19867	89.014	0.29553	89.030	0.38944	89.054	0.47945	89.085
90°	0.099831	90.000	0.19867	90.000	0.29552	90.000	0.38942	90.000	0.47943	90.000

Example of the use of Table: sinh (0.3/75°) = 0.29612/75.°432 = 0.29612/75.°25.'55"

NOTE.—sinh $\rho/\delta = 0/\delta$ when $\rho = 0$.

USE OF THE TABLES FOR HYPERBOLIC ANGLES BETWEEN 0.5 AND 1.0 IN MODULUS

Although the correcting factors $\frac{\sinh \theta}{\theta}$ and $\frac{\tanh (\theta/2)}{(\theta/2)}$, for reducing nominal to equivalent Πs, are only tabulated up to 0.5 in modulus of θ; yet, with a little extra effort, they can be used for lines whose hyperbolic angles do not exceed 1.0 in modulus. That is, they can be used for doubled range. It is evident that Table V is already sufficiently extended to apply to lines of

Digitized by Google

$\theta = 1$; since only the semi-angle $\theta/2$ in modulus has to be sought in it. It is only Table IV, therefore, which needs to be extended for the extra range. For this purpose, we may use the relation:

$$\frac{\sinh 2\theta}{2\theta} = \frac{\sinh \theta}{\theta} \cdot \cosh \theta \qquad \text{numeric } /\_\_$$

TABLE II
HYPERBOLIC COSINES

	0.1		0.2		0.3		0.4		0.5	
60°	0.99751	0°.249	0.99012	0°.999	0.97810	2°.267	0.96191	4°.075	0.94219	6°.460
61°	0.99736	0.244	0.98952	0.979	0.97674	2.221	0.95948	3.998	0.93838	6.343
62°	0.99721	0.238	0.98893	0.957	0.97541	2.173	0.95711	3.914	0.93465	6.217
63°	0.99707	0.232	0.98835	0.934	0.97411	2.123	0.95478	3.826	0.93099	6.083
64°	0.99693	0.226	0.98780	0.910	0.97285	2.070	0.95251	3.733	0.92741	5.941
65°	0.99679	0.220	0.98725	0.885	0.97163	2.014	0.95031	3.635	0.92393	5.789
66°	0.99666	0.214	0.98672	0.859	0.97044	1.955	0.94816	3.532	0.92054	5.631
67°	0.99653	0.207	0.98621	0.832	0.96927	1.894	0.94608	3.423	0.91725	5.463
68°	0.99641	0.200	0.98571	0.804	0.96814	1.830	0.94407	3.310	0.91407	5.288
69°	0.99629	0.193	0.98523	0.775	0.96706	1.764	0.94213	3.193	0.91100	5.106
70°	0.99617	0.185	0.98477	0.744	0.96601	1.696	0.94026	3.072	0.90805	4.916
71°	0.99606	0.177	0.98433	0.713	0.96500	1.626	0.93846	2.946	0.90521	4.718
72°	0.99596	0.169	0.98391	0.681	0.96404	1.553	0.93674	2.816	0.90248	4.513
73°	0.99586	0.161	0.98350	0.648	0.96313	1.479	0.93510	2.682	0.89989	4.302
74°	0.99576	0.153	0.98312	0.614	0.96227	1.402	0.93354	2.544	0.89742	4.085
75°	0.99567	0.144	0.98276	0.580	0.96145	1.324	0.93207	2.403	0.89508	3.861
76°	0.99559	0.135	0.98242	0.545	0.96068	1.244	0.93069	2.258	0.89288	3.631
77°	0.99551	0.126	0.98210	0.509	0.95996	1.162	0.92938	2.111	0.89081	3.396
78°	0.99544	0.117	0.98181	0.472	0.95929	1.078	0.92816	1.960	0.88889	3.155
79°	0.99537	0.108	0.98154	0.435	0.95866	0.993	0.92705	1.807	0.88711	2.910
80°	0.99531	0.099	0.98128	0.397	0.95808	0.908	0.92603	1.652	0.88548	2.660
81°	0.99525	0.090	0.98105	0.359	0.95756	0.821	0.92509	1.494	0.88399	2.406
82°	0.99520	0.080	0.98085	0.320	0.95710	0.732	0.92425	1.333	0.88266	2.149
83°	0.99515	0.070	0.98067	0.281	0.95670	0.643	0.92351	1.170	0.88147	1.888
84°	0.99511	0.060	0.98051	0.242	0.95635	0.552	0.92287	1.006	0.88044	1.624
85°	0.99508	0.050	0.98037	0.203	0.95605	0.461	0.92233	0.841	0.87957	1.357
86°	0.99506	0.040	0.98026	0.163	0.95580	0.369	0.92189	0.675	0.87886	1.087
87°	0.99504	0.030	0.98018	0.123	0.95560	0.277	0.92154	0.508	0.87830	0.816
88°	0.99502	0.020	0.98012	0.082	0.95545	0.185	0.92128	0.340	0.87790	0.544
89°	0.99501	0.010	0.98009	0.041	0.95537	0.093	0.92112	0.171	0.87766	0.272
90°	0.99500	0.000	0.98007	0.000	0.95534	0.000	0.92106	0.000	0.87758	0.000

Example of the use of Table: cosh $0.5/81° = 0.88399/2.°406 = 0.88399/2.°24.'22''$.
NOTE.—cosh $\rho/\delta = 1.0/0°$. when $\rho = 0$ whatever the value of δ.

Thus, suppose we require to find the value of the correcting-factor $\frac{\sinh \theta}{\theta}$ for the case of a line having a hyperbolic angle $\theta = 1.0/76°$ which is beyond the direct range of Table IV. Find in that Table the value of $\frac{\sinh \theta}{\theta}$ for 0.5/76, the semi-line angle, which gives 0.96368 /1°.138. Now find the cosine of

Digitized by Google

0.5/76 deg. in Table II. It is 0.89288/3°.631. The required value of $\frac{\sinh \theta}{\theta}$ for 1/76 deg. is then: 0.96368/1°.138×0.89288/3°.631=0.86045/4°.769.

Consequently, with the aid of this extra step, harmonic frequencies or lengths of line, can be dealt with extending up to 1.0 modulus in the line-angle θ.

TABLE III
HYPERBOLIC TANGENTS

	0.1		0.2		0.3		0.4		0.5	
60°	0.16017	59°.833	0.20133	59°.332	0.30444	58°.479	0.41037	57°.255	0.51983	55°.625
61°	0.10018	60.837	0.20140	60.345	0.30473	59.510	0.41107	58.305	0.52128	56.700
62°	0.10019	61.841	0.20148	61.360	0.30501	60.542	0.41176	59.359	0.52271	57.781
63°	0.10020	62.845	0.20156	62.375	0.30528	61.575	0.41244	60.417	0.52412	58.867
64°	0.10020	63.849	0.20164	63.391	0.30555	62.610	0.41311	61.479	0.52552	59.959
65°	0.10021	64.853	0.20171	64.408	0.30580	63.647	0.41376	62.544	0.52689	61.058
66°	0.10022	65.857	0.20179	65.425	0.30605	64.686	0.41441	63.612	0.52824	62.164
67°	0.10023	66.862	0.20186	66.443	0.30630	65.727	0.41504	64.685	0.52957	63.276
68°	0.10024	67.866	0.20193	67.461	0.30655	66.769	0.41565	65.760	0.53085	64.391
69°	0.10025	68.871	0.20199	68.486	0.30678	67.813	0.41623	66.837	0.53209	65.511
70°	0.10026	69.877	0.20206	69.501	0.30701	68.859	0.41680	67.918	0.53330	66.638
71°	0.10026	70.882	0.20212	70.522	0.30722	69.906	0.41735	69.002	0.53446	67.771
72°	0.10027	71.888	0.20217	71.544	0.30742	70.955	0.41788	70.089	0.53560	68.909
73°	0.10028	72.893	0.20223	72.566	0.30762	72.005	0.41838	71.179	0.53669	70.052
74°	0.10028	73.898	0.20228	73.589	0.30781	73.056	0.41886	72.272	0.53773	71.200
75°	0.10029	74.904	0.20234	74.612	0.30799	74.108	0.41932	73.368	0.53872	72.351
76°	0.10029	75.910	0.20239	75.635	0.30816	75.162	0.41975	74.466	0.53965	73.507
77°	0.10030	76.916	0.20243	76.659	0.30831	76.217	0.42016	75.566	0.54054	74.667
78°	0.10030	77.922	0.20246	77.684	0.30846	77.273	0.42054	76.668	0.54138	75.831
79°	0.10031	78.928	0.20250	78.709	0.30860	78.329	0.42088	77.771	0.54215	76.999
80°	0.10031	79.934	0.20254	79.734	0.30872	79.386	0.42120	78.876	0.54285	78.170
81°	0.10032	80.940	0.20257	80.759	0.30884	80.445	0.42150	79.983	0.54349	79.344
82°	0.10032	81.946	0.20260	81.785	0.30894	81.506	0.42177	81.092	0.54407	80.520
83°	0.10032	82.953	0.20263	82.812	0.30904	82.567	0.42201	82.203	0.54459	81.699
84°	0.10033	83.960	0.20265	83.838	0.30912	83.628	0.42222	83.315	0.54503	82.881
85°	0.10033	84.967	0.20267	84.864	0.30920	84.689	0.42239	84.427	0.54540	84.065
86°	0.10033	85.974	0.20268	85.891	0.30926	85.751	0.42252	85.540	0.54571	85.251
87°	0.10033	86.981	0.20270	86.918	0.30930	86.813	0.42264	86.654	0.54596	86.438
88°	0.10033	87.988	0.20270	87.946	0.30933	87.875	0.42274	87.768	0.54616	87.626
89°	0.10033	88.994	0.20271	88.973	0.30934	88.937	0.42279	88.883	0.54628	88.813
90°	0.10033	90.000	0.20271	90.000	0.30934	90.000	0.42280	90.000	0.54631	90.000

Example of the use of Table: tanh 0.2/70° =0.20206/69.°501 =0.20206/69.°30.′04″.
NOTE.—tanh $\rho/\delta = 0/\delta$ when $\rho = 0$.

Numerical Example. A three-phase transmission line has a length of 250 km. (155.34 statute miles), and consists of three No. 000 A. W. G. aerial copper wires, 0.41 inch (1.041 cm.) in diameter, supported symmetrically, on pole insulators, at a uniform interaxial distance of 72 in. (193 cm.). Required to find the equivalent Π of each wire, at an impressed sinusoidal frequency of 25 cycles per second. The following are the assumed linear constants of the line, referred to one wire:

Digitized by Google

Linear conductor resistance $r = 0.206$ ohm/km. $= 0.33$ ohm/mile.
Linear conductor inductance $l = 1.2223$ millihenry/km. $= 1.967$ millihenry/mile.
Linear dielectric leakance $g = 0$.
Linear dielectric capacitance $c = 0.0094828$ microfarad/km. $= 0.01526$ microfarad/mile.

TABLE IV

CORRECTING FACTOR $\frac{\sinh \theta}{\theta}$

	0.1		0.2		0.3		0.4		0.5	
60°	0.99917	0°.082	0.99670	0°.331	0.99257	0°.746	0.98685	1°.330	0.97956	2°.085
61°	0.99912	0.081	0.99645	0.324	0.99213	0.731	0.98603	1.302	0.97832	2.042
62°	0.99907	0.079	0.99625	0.317	0.99170	0.715	0.98523	1.273	0.97710	1.998
63°	0.99902	0.077	0.99605	0.309	0.99127	0.698	0.98448	1.243	0.97590	1.950
64°	0.99897	0.075	0.99585	0.301	0.99083	0.680	0.98373	1.212	0.97476	1.900
65°	0.99893	0.073	0.99570	0.293	0.99040	0.661	0.98300	1.179	0.97364	1.848
66°	0.99889	0.071	0.99555	0.284	0.99000	0.641	0.98232	1.144	0.97254	1.794
67°	0.99885	0.069	0.99540	0.275	0.98963	0.621	0.98165	1.108	0.97150	1.738
68°	0.99881	0.066	0.99520	0.265	0.98927	0.599	0.98100	1.070	0.97046	1.679
69°	0.99877	0.064	0.99505	0.255	0.98891	0.577	0.98035	1.030	0.96946	1.617
70°	0.99873	0.062	0.99490	0.245	0.98857	0.555	0.97975	0.990	0.96852	1.554
71°	0.99869	0.059	0.99475	0.235	0.98823	0.532	0.97918	0.948	0.96760	1.489
72°	0.99865	0.057	0.99460	0.225	0.98790	0.508	0.97863	0.905	0.96676	1.422
73°	0.99861	0.054	0.99445	0.214	0.98760	0.483	0.97808	0.861	0.96592	1.354
74°	0.99858	0.051	0.99435	0.203	0.98733	0.458	0.97758	0.817	0.96514	1.284
75°	0.99855	0.048	0.99425	0.192	0.98707	0.432	0.97710	0.771	0.96440	1.212
76°	0.99852	0.045	0.99415	0.180	0.98680	0.406	0.97665	0.724	0.96368	1.138
77°	0.99850	0.042	0.99405	0.168	0.98653	0.379	0.97625	0.676	0.96304	1.062
78°	0.99847	0.039	0.99395	0.156	0.98633	0.351	0.97585	0.628	0.96246	0.986
79°	0.99845	0.036	0.99385	0.144	0.98613	0.322	0.97545	0.578	0.96190	0.909
80°	0.99843	0.033	0.99375	0.131	0.98593	0.294	0.97512	0.528	0.96134	0.830
81°	0.99841	0.030	0.99365	0.118	0.98577	0.266	0.97483	0.477	0.96088	0.750
82°	0.99839	0.026	0.99360	0.106	0.98563	0.238	0.97458	0.425	0.96046	0.669
83°	0.99838	0.023	0.99355	0.093	0.98553	0.209	0.97433	0.373	0.96008	0.587
84°	0.99837	0.020	0.99350	0.080	0.98543	0.180	0.97413	0.321	0.95974	0.505
85°	0.99836	0.017	0.99345	0.067	0.98537	0.150	0.97395	0.268	0.95944	0.422
86°	0.99835	0.014	0.99340	0.054	0.98530	0.120	0.97380	0.215	0.95920	0.338
87°	0.99834	0.011	0.99335	0.041	0.98523	0.090	0.97370	0.162	0.95904	0.254
88°	0.99833	0.008	0.99335	0.028	0.98517	0.060	0.97365	0.108	0.95894	0.170
89°	0.99832	0.004	0.99335	0.014	0.98510	0.030	0.97360	0.054	0.95890	0.085
90°	0.99831	0.000	0.99335	0.000	0.98507	0.000	0.97355	0.000	0.95886	0.000

Example of the use of Table: $\frac{\sinh\ 0.3/80^\circ}{0.3/80^\circ} = 0.98593/0.^\circ 294 = 0.95893/0.^\circ 17.'38''$

NOTE. $\frac{\sinh \theta}{\theta} = 1.0/\underline{0^\circ}$ when $\theta = 0/\underline{\delta}$.

From these we obtain the following wire constants:

Total conductor resistance $R = 51.5$ ohms per wire.
Total conductor inductance $\mathfrak{L} = 0.30557$ henry per wire.
Total dielectric capacitance $C = 2.3707$ microfarads per wire.

At the frequency $f = 25$, the impressed angular velocity is $\omega = 157.08$ radians/sec. so that the total conductor reactance

Digitized by Google

$jX = j\mathcal{L}\omega = j\,47.999$ ohms per wire, and the total dielectric susceptance $jB = jC\omega = j\,3.72396 \times 10^{-4}$ mho per wire. The conductor impedance is $Z = 51.5 + j\,47.999 = 70.4/42°.985$ ohms per wire. The dielectric admittance is $Y = 0 + j\,3.72396 \times 10^{-4} = 3.7239 \times 10^{-4}/90°$ mho per wire. With these data, we obtain the nominal Π of each wire $A\,B\,G\,G$, Fig. 4.

TABLE V

CORRECTING FACTOR $\frac{\tanh\theta}{\theta}$

NOTE.—All the angles found in this table are negative

	0.1		0.2		0.3		0.4		0.5	
60°	1.0017	0°.167	1.0067	0°.668	1.0148	1°.521	1.0259	2°.745	1.0397	4°.375
61°	1.0018	0.163	1.0070	0.655	1.0158	1.490	1.0278	2.695	1.0425	4.300
62°	1.0019	0.159	1.0074	0.640	1.0167	1.458	1.0294	2.641	1.0454	4.220
63°	1.0020	0.155	1.0078	0.625	1.0176	1.425	1.0311	2.583	1.0482	4.133
64°	1.0020	0.151	1.0082	0.609	1.0185	1.390	1.0328	2.521	1.0510	4.041
65°	1.0021	0.147	1.0086	0.592	1.0193	1.353	1.0344	2.456	1.0538	3.942
66°	1.0022	0.143	1.0090	0.575	1.0202	1.314	1.0360	2.388	1.0564	3.836
67°	1.0023	0.138	1.0093	0.557	1.0210	1.273	1.0376	2.315	1.0591	3.724
68°	1.0024	0.134	1.0097	0.539	1.0218	1.231	1.0391	2.240	1.0617	3.609
69°	1.0025	0.129	1.0100	0.520	1.0226	1.187	1.0406	2.163	1.0642	3.489
70°	1.0026	0.123	1.0103	0.499	1.0234	1.141	1.0420	2.082	1.0666	3.362
71°	1.0026	0.118	1.0106	0.478	1.0241	1.094	1.0434	1.998	1.0689	3.229
72°	1.0027	0.112	1.0109	0.456	1.0247	1.045	1.0447	1.911	1.0712	3.091
73°	1.0028	0.107	1.0112	0.434	1.0254	0.995	1.0460	1.821	1.0734	2.948
74°	1.0028	0.102	1.0114	0.411	1.0260	0.944	1.0472	1.728	1.0755	2.800
75°	1.0029	0.096	1.0117	0.388	1.0266	0.892	1.0483	1.632	1.0774	2.649
76°	1.0029	0.090	1.0120	0.365	1.0272	0.838	1.0494	1.534	1.0793	2.493
77°	1.0030	0.084	1.0122	0.341	1.0277	0.783	1.0504	1.434	1.0811	2.333
78°	1.0030	0.078	1.0123	0.316	1.0282	0.727	1.0513	1.332	1.0828	2.169
79°	1.0031	0.072	1.0125	0.291	1.0287	0.671	1.0522	1.229	1.0843	2.001
80°	1.0031	0.066	1.0127	0.266	1.0291	0.614	1.0530	1.124	1.0857	1.830
81°	1.0032	0.060	1.0129	0.241	1.0295	0.555	1.0538	1.017	1.0870	1.656
82°	1.0032	0.054	1.0130	0.215	1.0298	0.494	1.0544	0.908	1.0881	1.480
83°	1.0032	0.047	1.0132	0.188	1.0301	0.433	1.0550	0.797	1.0892	1.301
84°	1.0033	0.040	1.0133	0.162	1.0304	0.372	1.0555	0.685	1.0901	1.119
85°	1.0033	0.033	1.0134	0.136	1.0307	0.311	1.0560	0.573	1.0908	0.935
86°	1.0033	0.026	1.0134	0.109	1.0309	0.249	1.0563	0.460	1.0914	0.749
87°	1.0033	0.019	1.0135	0.082	1.0310	0.187	1.0566	0.346	1.0919	0.562
88°	1.0033	0.012	1.0135	0.054	1.0311	0.125	1.0568	0.232	1.0923	0.374
89°	1.0033	0.006	1.0135	0.027	1.0311	0.063	1.0570	0.117	1.0926	0.187
90°	1.0033	0.000	1.0136	0.000	1.0311	0.000	1.0570	0.000	1.0926	0.000

Example of the use of Table: $\frac{\tanh\ 0.4/71°}{0.4/71°} = 1.0434\angle\overline{1.°998} = 1.0434\angle 1.°59.'53''$.

NOTE. $\frac{\tanh\theta}{\theta} = 1.0/\underline{0°}$ when $\theta = 0/\underline{\delta}$.

We next proceed to find the line angle θ as follows:

$$\theta = \sqrt{70.4/42°.985 \times 3.7239 \times 10^{-4}/90°}$$

$$= \sqrt{0.0262167\ /132°.985}$$

$$= 0.161915\ /\underline{66°.492}\ \text{hyp.}$$

Digitized by Google

Entering Table IV with the line angle $0.162/69°.5$, we find the architrave correcting factor to be $0.997/0°.18$. Also, entering Table V with the semi-line angle $0.081/66°.5$, we find the pillar correcting factor $1.0016\diagdown 0°.10°$. The corrected value of line impedance becomes therefore $70.4/42°.985 \times 0.997/0°.18 = 70.19/43°.165$, and that of each pillar admittance $1.862 \times 10^{-4}/90° \times 1.0016\diagdown 0°.10 = 1.865/89°.9 \times 10^{-4}$ mho. These values produce the equivalent Π of each line-wire, as shown in Fig. 5. That is, the external behavior of the actual line at any load could not be

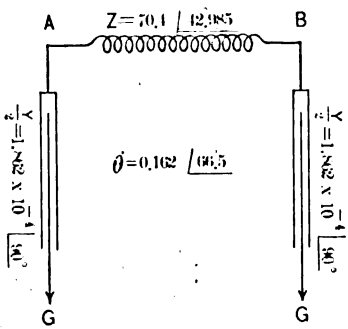


FIG. 4.—Nominal Π of line wire in numerical example

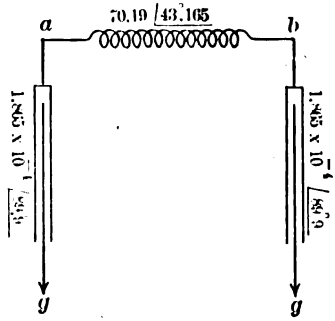


FIG. 5.—Equivalent Π of line wire in numerical example

distinguished from that of an artificial line of three equivalent Πs, each having, as architrave, an impedance coil of $70.19/43°.165$ ohms, and terminal pillar admittances, each of $1.865 \times 10^{-4}/89°.9$ mhos, such as might be produced by a condenser of 2.375 microfarads in series with a resistance of 9.73 ohms. The voltage regulation and efficiency of the three-phase line in the steady state of operation can now be determined by known methods, since the actual line is replaced by definite groups of reactance coils and condensers.

Digitized by Google

A paper presented at the Fort Wayne Section Meeting of the American Institute of Electrical Engineers, Fort Wayne, Ind., February 2, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

CENTRAL STATION GENERATION OF POWER AT MINING CENTERS

BY J. V. HUNTER

At the present time it is the well-known tendency of the electrical industry concerned in the production of commercial power, to produce this power in central stations of as large a capacity as possible consistent with the field to be covered, the object being to thus produce the power at the least possible cost. For this reason, every item of cost involved must be considered and attention must be given to each item of expense which will have a tendency to enable the producer to reduce the power cost. The cost of power production involves various items which may be classed under three general headings.

1. Fixed charges.
2. Labor.
3. Supplies.

The conditions involved in the first which will enter largely into the consideration of this paper are so well known that I will not attempt to give any definition of them, it being sufficient to say that they always bear a constant ratio of expense dependent upon the investment involved.

The conditions of the second are not within the province of this paper. They will enter in a general way into our consideration of power production cost, but only briefly so then, when we figure the expense due to power loss.

The third involves several items and it is with the major item of this group that I wish to deal in this paper; that is, the cost of fuel, the lesser items which make up this charge being water, oil and minor supplies which are included in the cost of main-

Digitized by Google

taining a power station. In a steam power station the fuel cost makes up from 85 per cent to 90 per cent of the cost of supplies. Few steam power stations of any considerable size have to face the necessity of purchasing their water. There are central stations at the present time in successful operation using oil as fuel, but in the central station line these make up but a comparatively small proportion of the total installations and are almost exclusively confined to those localities where oil is the most available fuel. The considerations involved in this paper will, therefore, be limited to the use as fuel of one of the different grades of coal or lignites. The use of the latter is still confined to the Western country and even there in relatively small quantities, but the approaching exhaustion of the high grade and easily workable seams in the Eastern coal fields, will in the future materially increase the value of the lignites as fuel. However, since at the present time there are in the Western country within reach of the lignite beds few if any power stations of any magnitude, I will at the outset eliminate the consideration of these beds from the work of this paper; though in passing it may be well to note that owing to the fact that lignite possesses nearly 50 per cent more weight for an equal heat value, the freight charges of transportation may be much worthier of consideration in this case than in others.

In taking up the subject of this paper, I did so because of the oft repeated statement largely in the popular semi-technical press, that it should be possible to more easily transmit power electrically than to pay freight transportation charges on the fuel necessary to produce this same power and certain writers have called attention to the use of the culm beds and other waste products in the mining regions of the East, which culm beds contain considerable fuel value, but not sufficient to make them worth shipping.

Facing the matter of fuel costs, we find that to the consumer this is made up of two factors.

1. The cost of coal at the mine.
2. The cost of transportation from the mine to the point of consumption.

With those central stations which use a very cheap grade of slack as fuel, the ratio of the first item to the second may be as high as 1 to 6. This, of course, implies the purchase of this slack coal at a very low price and its transportation for considerable distances involving high railroad charges. These railroad charges vary not only with the distance that the point

Digitized by Google

of consumption is located from the mine, but also to some extent depend upon the differential charges of the roads, which in some cases make great differences for comparatively minor distances. Especially in short distance hauls the railroad rates are more a matter of terminal charges than a question of the actual length of haul. For this reason the ton-mile charge for short distances will greatly exceed the ton-mile charge for long hauls.

As it was impractical to obtain the railroad rates from the coal fields to the general localities throughout the country, the cost of transportation has been limited to those railroad rates which were available, and the general average rate of charges per ton-mile for railroads as shown in the literature which has been brought out during the recent Inland Waterways Conventions. The statements presented in the last mentioned item showed that this cost ranged from 6 mills to $8\frac{1}{2}$ mills per ton-mile (1,460 kg-km.), depending upon the locality of the roads and the grades involved in the hauls. For my figures I shall use the minimum of these rates, that is an approximate cost of six-tenths of a cent per ton-mile (1,460 kg-km.), while those who know the actual freight rates in their own vicinity may compute the freight charges per ton-mile for individual cases.

In view of the cost of the fuel, as has been previously stated, and the factor which the railroad transportation charges have in its cost, the problem which will be considered in this paper is whether or not it would be a commercially practical scheme to locate the power stations at the mining centers, even at the doorway of the mine itself, and generating power in that locality, transmit it electrically to the point of consumption rather than pay the coal transportation charges on the fuel which would be necessary to produce the same amount of power.

Fig. 1 shows the known coal fields of the United States, the coal fields being indicated by the dotted areas. On this map the coal fields of special prominence owing to their productive capacity, though possible by no means the largest, are the anthracite fields lying in Eastern Pennsylvania, the semi-bituminous fields in Western Pennsylvania, West Virginia and Kentucky, the bituminous fields in Eastern Ohio, Indiana and Illinois, the low grade bituminous fields of Michigan and Missouri and contiguous localities and the lignite fields of Texas and North Dakota. There also exists a considerable coal area in

Digitized by Google

Rhode Island which has lately been brought to more or less prominence by several commercial schemes of exploitation as a mining investment, but as a fuel source with our present means of consumption, these coal fields will remain almost undeveloped. The coal is of a peculiar nature and of such structure, being high in ash and very low in volatile matter and also containing considerable graphitic carbon, that it requires intense heat for combustion and the volatile matters are insufficient to cause a continuance of combustion when once started, so that it is a very undesirable fuel for boiler and furnace work. Were this coal of better quality, it would doubtless have considerable influence as a fuel upon the New England region, but as it is,

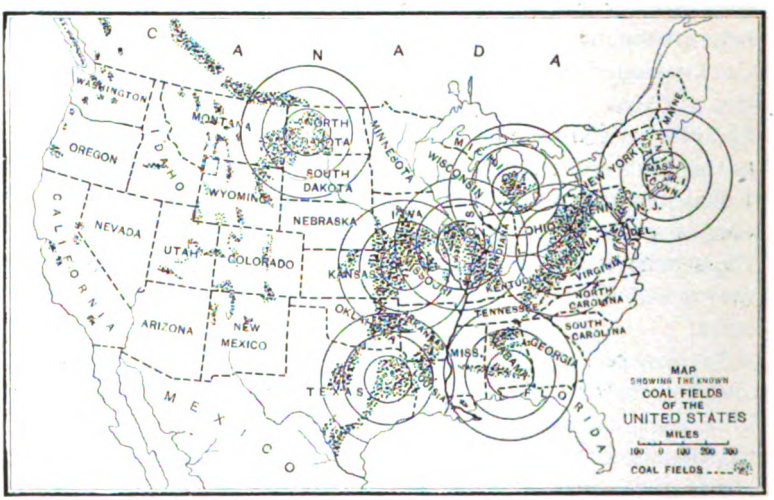


FIG. 1

most of the fuel supplies for this territory must come from the Pennsylvania fields. I have, however, included this field with the other fields in drawing the circles which are shown on the map at distances of 100 (161 km.), 200 (322 km.) and 300 (483 km.) miles, respectively from the approximate center of the mining region of each field. It must not be understood, however, that it is necessary to ship coal from this central region, nor that all freight rates are figured from this central region, for it may be equally possible to obtain as good or even better quality of coal from the veins lying at one of the extremities.

From this it may be seen that although New York City is not included in but one of the circles, it is nevertheless within a very

Digitized by Google

short distance of the coal fields of Eastern Pennsylvania and within about 200 (322 km.) miles of the coal fields of the western portion of the same state and whereas Fort Wayne on the map is only included within the 300 mile (483 km.) circles from West Virginia and central Illinois, it is well within the 200 mile (322 km.) circle should the center be taken in the Ohio coal fields and within the 100 mile (161 km.) regions if the center be taken in the Northern Indiana coal fields and Chicago is influenced in the same way being within little more than 60 miles (96.6 km.) of the fields of northern Indiana and Illinois.

In drawing these circles at the different mentioned radii, it was my idea to represent the possible length of transmission lines from these mining centers as indicated and to show what territory can be included within such distances, but as already stated, these mining centers are not to be taken as representing the position at which the most economically operated power stations should be located. They do represent what bearing the coal fields of the eastern states have relative to the manufacturing centers and they show that practically all the eastern and central states can be covered by transmission lines from some one of the coal fields. Thus we see that Indiana shows the possibility of power generation from three different fields. Portions of Illinois are covered in the same way, whereas the New England states are not only within striking distance of the worthless Rhode Island coal fields, but circles not shown, whose centers are in the Eastern Pennsylvania fields, would also cover a greater portion of the New England states; but although certain territories may be within reach of a number of coal fields, there would probably in all cases be the greatest advantage in giving one of the fields a preference over another, in some cases on account of the quality of the coal, or in the economy of line construction, or possibly owing to the character of the water supply, or due to anyone of the many engineering problems that develop in practice.

Those coal fields lying in the Eastern and Central states have already been exploited and opened up to such an extent that their possibilities as fuel producers are well known. The Missouri, Texas and Western fields containing low grades of bituminous and lignite fuels, are still only partially developed. In the field of the possibility of mining generation of power, provided the requirements were ever sufficient, these fields would quite probably offer the greatest inducement. This is due to

Digitized by Google

the fact that these fuels are of such low grade and have such poor storage and shipping qualities, that with considerable varieties it does not pay to mine, on account of the destruction and deterioration of the coal in shipping. Under such circumstances, it is manifest that any system which, at a reasonable cost, will permit the utilization of these fields for power purposes, would make valuable otherwise worthless fuels. In this instance it may be well to mention here the fact that the recent research work done by the Technological Branch of the United States Geological Survey developed the fact that these lignite coals can be successfully and cheaply briquetted in a manner to produce a fuel equal in many respects to high grade Eastern coals and that will stand shipping quite as well. The opportunity for producing a high grade fuel from these coals is afforded by the fact that they are relatively low in ash which cannot be removed by washing and that the briquetting process removes practically all moisture, which in a lignite may run as high as 35 per cent to 40 per cent. The result is that a coal rich in the volatile matters of high heat value hydrocarbons is produced. Probably these coals will eventually be used in gas producers in connection with gas engine plants, as they are undoubtedly adaptable to this consumption when the gas producers reach a stage of development to handle them, but since the gas engine station uses only one-third to one-half as much coal as a steam engine station, the cost of the necessary fuel will, therefore, be cut down in direct proportion.

The past engineering experiences in the construction of power lines covering great distances, undoubtedly show the possibility of the construction and operation of lines almost to any extent of our desires, but no matter what the construction, the question always remains " will it pay?", and it is to answer that question that the data for this paper was prepared. I must regret that the work contained in this cannot go as extensively into the subject of freight rates as I would desire, for I found it difficult to obtain much subject matter upon these rates and the only ones at my disposal were those to Fort Wayne and to Chicago, but even considering these would show the practicability in some cases of this scheme of transmission, the practicability in all cases depending greatly upon the quantity of power consumed, as one of the accompanying tables will show.

Owing to the lack of sufficient freight rate data, as before stated, I decided to so arrange the accompanying table that it

Digitized by Google

would not show what would be the actual comparative costs from the different mining centers to the centers of manufactory, as one might suppose, by merely glancing at the map, but rather have made this on a basis of cost for a 100-mile (161 km.) circuit from the point of production of power at the mine to an empirical point of power consumption 100 miles (161 km.) distant and for this distance I have made an allowance of 0.6 cent per ton-mile, (1,460 kg-km.) for the cost of transporting the coal and have used the cost found in this way to compare with the fixed charges on maintaining a transmission line for an equal distance. I may say here that the best figures I have on this coal transportation shows that it may run a little above 0.6 cent for as short a distance as 100 miles (161 km.), but when the distance runs up nearly to 200 miles (322 km.) this may in some cases fall to almost as low as 0.4 cent, but I found this to be true only in a few cases in Illinois and the charge is doubtless due to the fact that for this greater distance the terminal charges remain the same and the haulage distance only is varied, while it has been shown conclusively on many occasions that the terminal charges make up a good share of transportation costs.

The accompanying table was then prepared for the five station capacities as shown. It was my intention, if possible, to show a curve which might indicate that at some capacity it would begin to show economy in transmitting power and that below that capacity such transmission would involve a loss. This is in fact shown, for the saving at the 10,000-kw. station capacity is only a little over $5,000 a year and if this capacity should fall below 10,000 kw. it would not have to go far before the fixed charges would more than equal the coal transmission charges, as is shown on the capacity of 5,000 kw. a year where the fixed charges given show a considerable loss for transmission.

The first item was figured as the cost of a right-of-way 50 ft. (15.3 m.) in width extending the entire distance at an average cost of $100 per acre (0.405 hectares). No increase in the width of the right-of-way was made for the power capacities of 60,000 and 80,000 kw., although these require a double tower construction and it would rather crowd things to put these in a 50-ft. (1.53 m.) right-of-way. Standard figures were used in obtaining the second item of the cost of the steel tower construction per 100 miles (161 km.). The towers were figured for twin circuits, although the copper figures only allow for twin circuits on the line of towers for the 40,000-kw. line, twin circuits

Digitized by Google

for one line of towers on the 60,000-kw. and single circuit on the other line of towers and twin line of conductors on the double line of towers in the 80,000 kw. capacity. These approximate estimate of costs were taken from one of the standard works upon this subject. The conductors were figured for the most economical copper and line losses as indicated in the calculations for transmission lines, as was recently published in the *General Electric Review*. The system as outlined there was followed

COMPARATIVE COST OF FIXED CHARGES INVOLVED IN POWER TRANSMISSION AND FREIGHT CHARGES OF FUEL TRANSPORTATION

Power station at mines: Distance 100 miles form point of consumption

Freight—$0.006 per ton-mile. Coal 4.0 lbs. per kw-hr.

Central station capacity	5,000 kw.	10,000 kw.	20,000 kw.	40,000 kw.	60,000 kw.	80,000 kw.
Right of way Cost per 100 miles 50 ft. wide	$60,000 @ 5% $3,000	$60,000 @ 5% $3,000	$60,000 @ 5% $3,000	$60,000 @ 5% $3,000	$60,000 @ 5% $3,000	$60,000 @ 5% $3,000
Steel tower const'n. Cost per 100 miles. Twin circuit towers not including copper	$332,200 @ 9% $29,898	$332,200 @ 9% $29,898	$332,200 @ 9% $29,898	$332,200 @ 9% $29,898	double pole line $664,400 @ 9% $59,796	$664,400 @ 9% $59,796
Conductor Cost for most economic line. Copper @ 14c.lb.	$70,000 @ 6% $4,200	$140,000 @ 6% $8,400	$280,000 @ 6% $16,800	$560,000 @ 6% $33,600	$840,000 @ 6% $50,400	$1,120,000 @ 6% $67,200
Kw-hr. loss on line Cost of $0.003 per kw-hr	$4,857	$9,714	$19,428	$38,856	$58,284	$77,712
Transformers Equal capacity at each end of line to carry load. Cost $15.00 per kw	$150,000 @ 15% $22,500	$300,000 @ 15% $45,000	$600,000 @ 15% $90,000	$1,200,000 @ 15% $180,000	$1,800,000 @ 15% $270,000	$2,400,000 @ 15% $360,000
Total of fixed charges and losses	$64,455	$96,012	$159,126	$285,354	$441,480	$567,708
Freight charges One year's coal supply	$50,580	$101,160	$202,320	$404,640	$606,960	$809,280
Loss by transportation of fuel	$13,875*	$5,148	$43,191	$119,286	$165,480	$241,427

*Loss by transmission.

exactly. The cost of the kilowatt losses on the line were figured according to the values already derived for the most economical loss. The cost per kilowatt-hour was computed at 0.3 cent. which may seem rather low but will probably be very near a fair value for a high grade station of these capacities in view of the fact that the cost of coal will be nothing more than the mining charges. The transformers are, as a matter of course, necessary to handle the voltage at each end of the line, it requiring two sets of trans-

Digitized by Google

formers, each equal in capacity to the station. The cost of these was roughly approximated at $15 per kw. The interest and depreciation allowed on these was 15 per cent. The constant for the freight charges on the coal has already been shown but in calculating the quantity of coal required, this was done on the basis that with a high grade station, one kilowatt could be produced for each four lbs. (1.81 kg.) of coal burned. The freight on this quantity of coal was then calculated at a rate of 60 cents per ton (907.2 kg.).

One further note I must make is that these figures were calculated for a constant power load of 24 hours a day. Inasmuch as the figures shown in the table will speak for themselves, it is unnecessary for me to attempt to make any comments and one may draw his own conclusion. I know of no power station at the present time operating under such conditions of avoidance of freight rates, but provided these rates continue to advance, as they have shown a tendency to do, the time may come when the central station men will be forced to this recourse in self-defence.

Digitized by Google

Digitized by Google

WATER POWER DEVELOPMENT.

A BRIEF PREPARED BY THE PUBLIC POLICY COMMITTEE AND ADVISORY MEMBERS OF THE A. I. E. E., AND PRESENTED AT THE PUBLIC HEARING BEFORE THE U. S. NATIONAL WATERWAYS COMMISSION, WASHINGTON, D. C., NOV. 21, 1911.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

33 WEST THIRTY-NINTH STREET, NEW YORK

PUBLIC POLICY COMMITTEE
HENRY G. STOTT, CHAIRMAN
H. W. BUCK
JOHN J. CARTY
GANO DUNN, EX-OFFICIO
JOHN H. FINNEY
CHARLES W. STONE
CALVERT TOWNLEY
JAMES G. WHITE

ADVISORY MEMBERS
EDWARD D. ADAMS
PHILIP P. BARTON
LOUIS BELL
DUGALD C. JACKSON
WILLIAM S. LEE
LEWIS B. STILLWELL
PERCY H. THOMAS

November 17, 1911.

To the Honorable

The United States National Waterways Commission:

SIRS:—

Under the instructions of the Board of Directors of the American Institute of Electrical Engineers, its Public Policy Committee, with which have been associated Advisory Members who are experts on the development and electrical transmission of water powers, has the honor to respond to your invitation to attend the public hearing set for November 21, at Washington, and to put at the disposal of the Commission its services as experts in any electrical engineering or closely allied questions the Commission may refer to it.

The function of the American Institute of Electrical Engineers is scientific and professional, and is not commercial; consequently, its committee refrains from expressing itself on the commercial, industrial, legal or political aspects of the water

Digitized by Google

power situation, except when these are incidental to the effect of that situation upon the practice of electrical engineering which it is the Society's object to promote. It appreciates also that the Commission is probably desirous not of the views of particular individuals, which might represent only individual opinions, but would be glad to have before it such opinions as are shared by a group of experts and may therefore be regarded as representative and out of the field of controversy. It has therefore prepared a statement of such opinions on a number of electrical engineering and closely allied questions related to the development of water powers.

In anticipation of the raising of some or all of these questions by members of the Commission, it respectfully submits this statement embodying its joint opinions for the Commission's consideration. It would call attention to the fact that prominent electrical engineers have for a number of years been contributing to the TRANSACTIONS of the American Institute of Electrical Engineers papers bearing on all phases of the water power question, and that the subject is one of vital interest to the American Institute of Electrical Engineers because the whole character of water power development has been changed from that of a local enterprise to that of a great public service utility by means which electrical engineers have provided, and the utility and development of water power depends almost entirely upon the fact that it may be transformed into electric power.

RELATION OF WATER POWER TO NAVIGATION

That the utilization of rivers and smaller streams for navigation and for the development of power are naturally interrelated is obvious. As regards by far the greater part of our undeveloped water powers on the public domain, the ultimate value as sources of power of those streams is vastly greater than any possible value which could be realized by attempts to utilize them as channels for navigation, but in the case of many of our larger rivers the possibilities of development for purposes of navigation predominate as compared with power development. The committee recognizes the fact that in all cases where practical possibilities of both navigation and power development exist the two objects in view are coöperative and not antagonistic—the construction of the dams and locks necessary to secure navigability affording a natural and generally effective means of developing the power of the streams.

Digitized by Google

Water Power a Public Utility

Modern water power developments usually are not local private enterprises, as is generally supposed. The developments in recent years in the electrical transmission of power have made possible the distribution of electric power from a single water power plant over territories embracing in some cases over 40,000 square miles in area, supplying electric power for diversified purposes to hundreds of thousands of people. Such distribution of water power is an advantage to the consumers, and any policy tending to retard or handicap the development of water powers is a disadvantage to the people in the surrounding territory and retards its industrial development.

The regulation of public utilities by public service commissions has become practically an accepted principle in the United States, and there is no reason why safeguard from unfair charges for water power should not be found by this means, especially where the wide area covered by electrical distribution makes the public nature of a water power obvious.

Distribution of Investment in Hydroelectric Systems

The investment of capital in hydroelectric systems is not confined to the dam and power house. In general, not over fifty per cent of the investment is represented in the generating plant, the balance representing the cost of the transmission lines radiating from the plant, the substations at the ends of the transmission lines for the conversion and distribution of the transmitted power, and the secondary distribution lines delivering power from the sub-stations to the premises of the various consumers. The distribution system outside of the power plant, while not apparent to the casual observer of a power house and dam, represents in many hydroelectric developments the greater part of the total investment.

Close Competition Between Water Power and Steam Power

The belief among certain classes of the public that water powers yield excessive or disproportionate profits springs primarily from two causes—the conception that the water itself is the power and that the expenses of operation of a water power are small while the company's income is large.

While, certainly, the power could not be developed without the water, the water on its part can deliver no power except

Digitized by Google

by means of the dam, the power house, and its appurtenances. It is difficult for the public to regard these once built as involving continuing expense, but they do. This expense is comparable in amount with the cost of coal in a steam station, and is the return due to the capital invested. It takes the form of interest, sinking fund expenditures, depreciation and taxes. The invested capital in a water power is so much greater than the public realizes, that with interest charges at not more than five or six per cent, in a majority of cases, from seventy to eighty per cent of a water power company's income is absorbed.

This return to capital is not profit. Without the prospect of it, capital cannot be secured.

Of a water power once built and after its expected market has been developed, the operating expenses, exclusive of the returns to capital, are seen by the public to be small, which they are, in a majority of cases, absorbing only from fifteen to twenty per cent of a company's income. The remainder, however, that is left for profit after capital and operating charges are paid is usually not large and certainly not excessive, especially when there is always risk of damage from floods, lightning, failure of expected market to develop, and such uncertainties of operation as the art of electrical engineering has not yet been able completely to remove.

Practically all water powers come to birth or not on the answer to the question " What is steam power in the territory costing?", and they can only live when they deliver power at a substantially lower cost. At the same cost, they remain unborn.

Besides the cost of power, the relative amount of investment is a determining factor. While at present a steam electric plant can be built for $75.00 per horse power the cost of a hydroelectric plant varies from two to four times that amount. Part of this difference is because the steam plant can be built near the center of its market, while the water power is almost invariably at a distance.

With the capital required for a water power so much greater, the tendency is to build a steam plant, even if the power it delivers is not as cheap as that of a water power. If it can be shown that water power can be delivered for, say, $25.00 per horse-power per year, but that steam power can be produced for, say, $27.00, the water power plant will not be built, and the steam power will. If, however, the water power could be delivered for $24.00, the difference might turn the tide in favor of the hydroelectric investment.

Digitized by Google

It is because of the great effect of slight differences in the cost of water power upon the determination of the question "Shall water or steam power be developed in a given community?" that even light burdens in the form of taxation, charges for sinking fund to wipe out the investment at the end of a limited period, or limitations as to tenure even though not immediately onerous, loom so large in settling it.

Attention is often called to the increasing cost of coal with an implication that the cost of steam power will rise, permitting hydroelectric companies to raise their rates and exact undue profits. The implication is not correct. It is true that the cost of coal is rising, but it is also true that steam engines and boilers are constantly being improved in efficiency, and that the art of producing power from steam is progressing at a rate so much more rapid than that at which the price of coal is rising that the cost of steam power is continually falling. Should a limit to this fall be reached, which is not yet in sight, gas and oil engines are making such constant reductions in the cost of power that there is no probability that water powers will be free from the controlling competition of other kinds of prime movers. It is safe, to say that extortionate rates in water power are highly improbable even if the principle of rate regluation by commission were not applicable to hydroelectric companies.

Construction Risk in Hydroelectric Development

While hydroelectric engineering is tending toward more standard methods of construction, each individual development will present new problems in engineering with the inevitable construction risk connected therewith. During construction the works are constantly subject to serious damage by abnormal floods, and unexpected difficulties and physical conditions may arise whereby the cost of construction may be very materially increased beyond original expectations. Furthermore, after the power plant itself is satisfactorily completed, the success of the enterprise is commonly dependent upon the industrial development of a large territory surrounding the power plant upon which it relies for its market for power. Such industrial growth can only be predicted on general principles, and may be subject to unexpected retardation due to industrial depression or other unforeseen causes. Again, unexpected competition may develop from new and improved steam and other engines, all of which limit or defer the profits of the

Digitized by Google

enterprise. On account of these engineering and operating risks and uncertainties capital which is invested in hydroelectric enterprises is entitled to reward commensurate with the risk.

Revocable or Limited Term Permit

The revocable permit for the construction of a hydroelectric system does not attract capital because of the obvious uncertainties involved. In case of revocation, not only would the power plant and dam be forfeited, but all of the transmission lines, substations, and distribution system dependent thereon for their operation jeopardized. Not only is it difficult to induce capital to invest in such a development based upon a revocable permit, but it is very difficult to close the long term power contracts with consumers which are necessary to make a hydroelectric system financially successful. Consumers are unwilling to make their future business requiring power dependent upon a permit which might cause at any time the complete disorganization of the system supplying their power.

A limited term franchise also involves financial and engineering difficulties which seriously impede the normal development of a progressive hydroelectric system. Such systems are laid out from their inception for ultimate growth, and in this respect are comparable to large railway systems. The transmission lines are constantly reaching out into new territory in order to meet new demands and with the development of the art it is necessary to make investments in extensions in order to maintain satisfactory service and to meet the demands of power consumers.

With a limited definite term beyond which renewal of rights are uncertain, no company would be willing to continue indefinitely the extension and improvement of a system so necessary and desirable from the standpoint of public service. The necessity of writing off not only the original cost of the plant, but the continual annual investment in additions thereto within the limited term of the permit requires an annual sinking fund that adds materially to the cost of the water power. This is a hardship, not only upon the power company, but upon the consumer.

Before the end of such limited permit development of the system would cease, maintenance expenses would be cut to a minimum, and the plant would deteriorate to a point where the service to the public would become unsatisfactory.

Digitized by Google

Interconnection of Contiguous Hydroelectric Systems

It has been suggested that with the growth in extent of large hydroelectric distributing systems ultimate interconnections and combinations between them might establish a monopoly and permit the raising of prices for power.

Such interconnection between contiguous hydroelectric systems offers decided and important engineering advantages. It improves the constancy of electrical pressure and enables the system to draw power from two or more independent power plants.

The rain-fall occurring at different times on two or more separate watersheds are thus made to benefit all of the consumers on the combined systems.

Such interconnection also permits reduction in operating expenses and assures better service by reducing to a minimum the probability of total interruptions at any time from line troubles or otherwise.

The investment and consequently the cost of power can be reduced by combination, because less capacity in generating machinery to serve as spare plant for emergencies need be installed, and operating expenses can be reduced by rendering repairs easier, owing to greater facilities for shutting down for work or for inspection. Any tendency towards raising the price of power as an accompaniment of such combination is restrained automatically by competition with steam power, and can be regulated by government commission.

Extent of Water Power Development

The statistics of water power collected under the direction of Congress several years ago and embodied in the Report of the National Conservation Commission of 1909, show that there is at present developed in the United States about five million horse-power of water power.

The amount of power produced by steam from coal is difficult to estimate, but is considered to be about 27,000,000 horse-power, and is rapidly increasing with attendant depletion of coal reserves. A large part of this it is not only possible but easy for water power to replace if it were made freely available through development. Within range of development at a cost of investment that would make the cost of such power about equal to that of steam power, there is still undeveloped in the streams of the United States about 35,000,000 horse-power.

Any action by Congress that would accelerate the release of

Digitized by Google

this power would conserve enormous supplies of coal for such domestic and industrial purposes, as only coal can supply.

Conclusion

We regard it beyond our province to urge upon the Commission specific measures or to discuss other than incidentally phases of the water power question not involving electrical engineering. What we have given are, in our opinion, engineering and economic facts on which the Commission may rely.

Henry G. Stott,
Chairman.

Digitized by Google

A paper to be presented at the 266th meeting of the American Institute of Electrical Engineers New York, December 8, 1911.

Copyright 1911. By A. I. E. E.

(Subject to final revision for the Transactions.)

METHODS OF VARYING THE SPEED OF ALTERNATING-CURRENT MOTORS*

BY GUS A. MAIER

Electrical developments of recent years have been toward the extension of the use of alternating currents in every field where practicable, due to the advantages of distributing systems and the simplicity of the induction motor. For constant speed work, the field is well covered by the squirrel cage and polar wound motors. Various methods have been proposed for varying and adjustable speed work and this paper is to discuss the methods used and proposed.

VARYING SPEED

For varying speed work the following types of motors have been used.

Induction.

Squirrel cage (resistance control).
Squirrel cage (compensator control).
Double squirrel cage with one movable stator.
Sliding armature.
Polar wound armature.

Commutator.

Repulsion (resistance).
Repulsion (brush shifting).

* A number of papers have been written on the individual methods of varying the speeds of alternating-current motors. No effort has been made to go into details of design or to discuss broadly those subjects which have recently been treated. Free use has been made of papers and all articles referring to this subject. This paper covers in a general way the methods of varying the speeds of alternating-current motors.

Digitized by Google

For adjustable speed work the following have been used:

Induction.

Multispeed { Pole changing. Frequency changing. Cascade.

Commutator.

Shunt repulsion.

Induction in connection with shunt repulsion.

Induction Motors. The two principal methods of obtaining varying speed with induction motors are; first, primary control (varying the stator voltage of a motor having a high resistance rotor); and second, by secondary control (varying the rotor resistance). The first can be subdivided depending on whether the variation in the stator potential is obtained through a compensator or a resistance in the primary circuit of the motor.

The starting torque of an induction motor is equal to

$$K\left(\frac{E^2 r_1}{Z^2}\right)$$

Where K = a constant.
E = applied voltage.
r_1 = rotor resistance per phase.
Z = total impedance.

The starting current is equal to $\frac{E}{Z}$.

The running torque is equal to

$$K\frac{E^2 S r_1}{[(r_1+Sr)^2+S^2 X^2]}$$

Where X = total reactance.
r = stator resistance per phase.
s = slip.

It is thus directly dependent on the rotor resistance, the slip and the square of the voltage, and inversely on a function of resistance, slip and reactance.

Fig. 1 gives a comparison between the percentages of full-load torque and current at various percentages of synchronous speed for the two methods of speed variation. For full-load torque at starting, $2\frac{1}{4}$ times full-load current is taken from the

Digitized by Google

line with resistance control and 1.4 times full load current with compensator control.

A squirrel cage rotor designed for this service is necessarily very expensive, as the losses necessary to obtain the reduced speeds are all within the machine and, therefore, a large motor is necessary. Compensator control is complicated and expensive, owing to the fact that the compensator coils must be cut out and cannot be short circuited, as is the case with rheostatic control.

The sliding armature control, in which the rotor is displaced

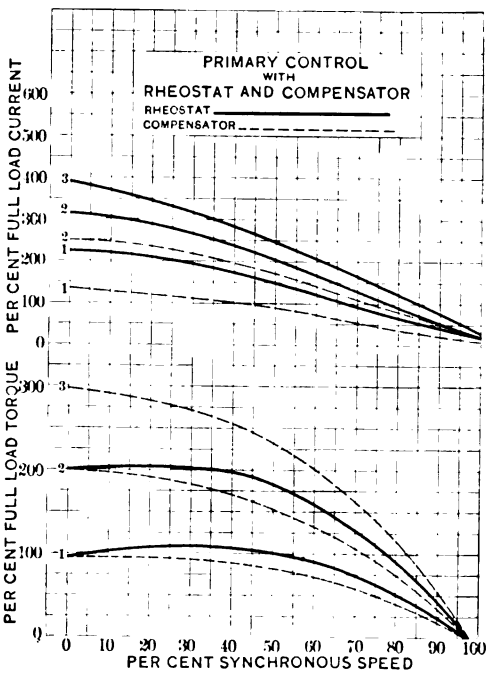


FIG. 1

horizontally with respect to the stator and the double squirrel cage with one movable stator have the same limitations and characteristics, as noted above.

The polar wound induction motor with variable rotor resistance is best adapted to variable speed, as the losses necessary to obtain reduced speeds are external to the motor itself. The primary current is approximately proportional to the torque, full load for full load torque. See Fig. 2.

The main objection to this type of motor even though the

Digitized by Google

speed characteristics are satisfactory is the efficiency at reduced speed, the efficiency being reduced in direct proportion to the reduction in speed.

By comparing Fig. 1 and Fig. 2, you will note that in curve No. 3, the torque per ampere is the same for all three methods of control. This is because the total resistance in the polar wound rotor circuit, on this point of the controller, is equal to the resistance of the high resistance squirrel cage motor. It is of further importance to note the very much better inherent speed

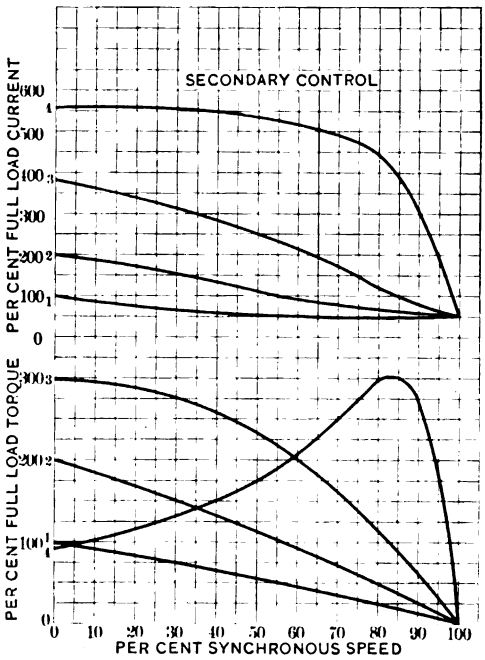


FIG. 2

regulation of the polar wound motor over other methods of control.

Referring to Fig. 3 it is important to note the advantages of the polar wound equipment as compared with the other two methods. The current taken from the line is less, the power factor higher and the efficiency high throughout practically the entire range. Furthermore, the slip is less; the final slip shown by the resistance and compensator control is due to the use of high resistance squirrel cage windings.

Digitized by Google

Commutator Motors. The operation of single-phase alternating-current commutator motors can be explained in a simple manner by comparison with direct-current commutator machines. In each direct-current machine, the torque is developed by the resultant of the current flowing in the armature bars and the field in quadrature thereto. In case such a motor is supplied with alternating current, then also a torque will be exerted.

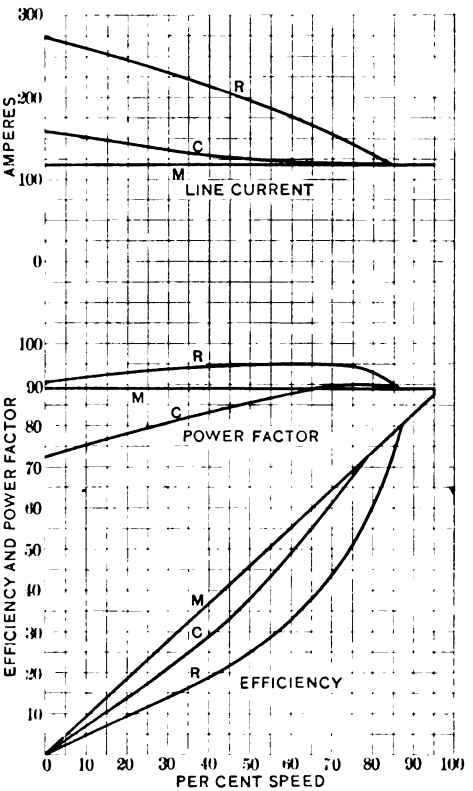


FIG. 3

Due to the alternating nature of the current and voltage, both field and armature current will fluctuate, passing through all intermediate values between maximum and minimum, and a pulsating instead of a constant torque will exist. In case field and armature circuit has been connected in series, the variation of the instantaneous values of field and armature current will be in complete time phase and the torque will never reverse;

Digitized by Google

for a reversal of torque, it being necessary that either the direction of the field or the direction of the armature current be changed, as is known from direct current practice. The possibility of driving a direct-current motor with alternating current was discovered by Dr. Louis Duncan.* By connecting the field and armature circuits in multiple, the torque will be considerably reduced, the current in both circuits differing in time phase, due to the difference of the self inductance of the two circuits. Hence, it even can happen that at the moment the armature current has just passed through its zero value, the torque is reversed. In a direct-current machine from the magnetic lines interlinked with the armature conductors, a flux will result, which is in quadrature to the field when the brushes are standing in the neutral. This flux decreases the perfection of the operation by distorting the shape of the main field and by inducing in the windings—short circuited under the brushes—and e.m.f. of rotation which can give rise to sparking. In

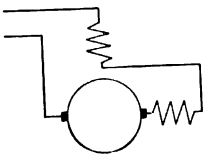


FIG. 4

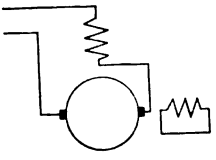


FIG. 5

modern direct current design, the armature flux usually is compensated by a special compensating winding or by interpoles. With alternating-current motors such a compensating winding is rarely omitted since the armature flux in this case also lowers the power factor by inducing a reactive voltage. This will be readily understood by considering that in an ordinary induction motor, the reactance is nearly exclusively caused by leakage lines inside the slots, from teeth to teeth and around the end connections, while in a commutator motor, the number of leakage lines is largely increased by the flux which finds a path of low magnetic reluctance in the field core. By using a cylindrical core instead of polar field, the influence of the armature flux is increased. The compensation of the armature flux can be obtained in the same way as the direct-current motors, by connecting the armature and compensating winding in series. (Compensation by conduction). See Fig. 4.

* See TRANSACTIONS, A. I. E. E., 1888, Vol. V, p. 211.

Digitized by Google

The compensating winding can be closed upon itself in which case the compensation is obtained by induction as shown in Fig. 5. Compensation by induction is also possible by connecting field and compensating winding in series, in which case the armature current is induced in the short circuited armature, Fig. 6.

With the arrangement according to Fig. 5, the e.m.f. induced in the short circuited winding equals the product of current times impedance, while in the arrangement according to Fig. 6, in addition thereto, there has to be transferred from the compensating winding into the short circuited armature winding, an e.m.f. which is balanced by the e.m.f. generated by rotation of the armature conductors in the magnetic field.

Fig. 6 at the same time represents a type of repulsion motor, which, in its original form, as invented by Elihu Thomson in 1887, has but one stator winding, the axis of which is displaced over a certain angle to the axis of the brushes. (Fig. 7). In

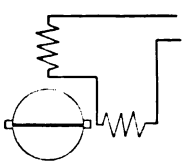


FIG. 6

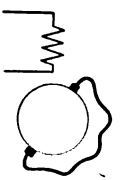


FIG. 7

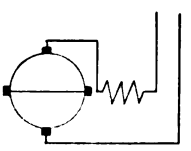


FIG. 8

this case, in order to investigate the operation of the machine, we can always replace this single winding by two imaginary windings, so as to have the conditions outlined in Fig. 6.

Instead of providing on the stator both the field and the compensating winding, as outlined in Fig. 6, the field winding can be omitted if we place on the armature two brushes in quadrature to the short circuited brushes, and connect the compensating winding in series with the brushes, which may be called field brushes. (See Fig. 8.)

This arrangement covers the principle of the compensated repulsion motor, which was invented by Winter and Eichberg in Germany, and La Tour in France. In any motor, in which the armature flux is compensated by induction, the compensating winding and armature winding act as the primary and secondary of a transformer. Hence, as in any transformer, a flux lagging over 90 deg. in time phase behind the primary energy current

Digitized by Google

will exist. This flux, which may be called " cross flux " can be made effective in improving the commutation of the armature current. In the compensated repulsion motor, apart from this effect, the cross flux generates an e.m.f. of rotation which compensates the self induction of the armature field circuit and also of the stator winding when connected in series to the armature field winding. When bearing in mind that between the brushes of a revolving armature, only an e.m.f. of rotation can be induced by a field winding, the axis of which is standing in quadrature thereto, and that this e.m.f. will always be in time phase with the field current in which the armature is rotating, it will be understood that between the exciting brushes only the cross flux interlinked with the compensating winding can induce an e.m.f. of rotation, and that between the short circuited energy brushes, only the flux interlinked with the armature field winding can induce an e.m.f. of rotation. Apart from the above outlined improvement, resulting from the introduction of field brushes on the commutator, the compensated repulsion motor does not differ from the other mentioned types of single-phase commutator machine.

To supply a motor with energy current, counter e.m.fs. have to be overcome. Of these, there are both useful and harmful. Of the useful there is chiefly the back e.m.f. induced in the rotor by rotation in the motor field, for the motor output is proportional to the product of this e.m.f. and the energy current. On the other hand, the counter e.m.f. of self induction of the rotor winding is injurious and can practically prevent any appreciable energy current flowing. It is, therefore, necessary to neutralize the inductance of the rotor winding along the brush axis and reduce the inductive pressure to a minimum. This is accomplished by means of a compensating winding on the stator, the axis of which is arranged along the brush axis. The winding is traversed by the rotor current or current proportional to this and serves to neutralize the armature field, the effective ampere turns being adjusted to secure this result. Thus we see that the compensating winding is an essential part of the commutator motor and the same can be either a separate winding or combined with the exciting winding.

Hence, in regard to speed control, the motors covered by Fig 4 to Fig. 8 can all be considered as direct current series, and the method used for speed regulation of the same can be applied.

Digitized by Google

Primary Voltage Control

Assuming constant torque, in which case the current has to be constant, the e.m.f. induced between the armature energy brushes will increase in the same ratio as the speed. Hence, since the requirement has to be fulfilled, that the voltage applied to the armature (either by conduction or induction), be equal to the resistance drop and the e.m.f. of rotation; the voltage applied to the terminals has to be raised in order to reach this condition. By connecting the terminals of the motor covered by Figs. 4 to 8 to a transformer with variable taps or to an induction regulator, the applied voltage can be changed and the speed regulation obtained. The principle has been demonstrated in Fig. 9, for compensated series motor according to Fig. 4.

Primary Resistance Control

Instead of using a transformer with variable ratio of transformation, the reduction of the voltage can also be obtained

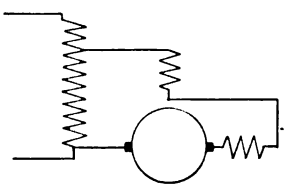


Fig. 9

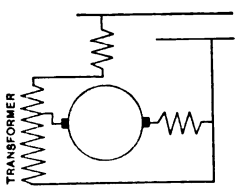


Fig. 10

by inserting resistance between the line and the motor terminals. This method is less efficient than the former, however, due to simplicity of the required control apparatus, can be used for small units and control during short periods.

Field Control

By connecting in parallel to the field variable resistance or by connecting the field to the secondary of the series transformer with variable taps, the ratio of field current to armature current can be changed and thus, the speed of the motor would be regulated.

Armature Voltage Control

This method is in principle the same as the methods described under the heading " Primary Voltage Control ", the only difference being that the armature is directly connected to the secondary of a transformer, which is laying in series with the field winding. (See Fig. 10.)

Digitized by Google

Brush Shifting

The brush shifting commutator motor is built both single and three-phase. On account of simplicity, the single-phase will be described.

The single-phase motor of this type is known as the Deri type or modification thereof, and is used for hoists, railway work, and in fact, such places where a motor with series characteristics is applicable.

The torque of a motor depends on the diameter and axial length of its rotor, on the number of conductors, the current and the field. The torque is commonly varied by variations in the current and field strength, but in the type of repulsion motor provided with brush displacement gear, it is also possible to vary the ratio of active field conductors to active rotor conductors.

By shifting the brushes out of the neutral, that is, by reducing

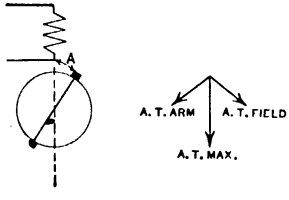


Fig. 11

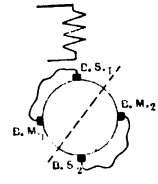


Fig. 12

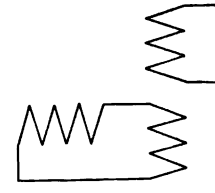


Fig. 13

the number of active conductors in which an e.m.f. is induced by rotation with the same field strength, the speed has to be increased in order to induce the same e.m.f. of rotation which again has to balance the energy voltage.

In regard to brush shifting, special reference should be made to the motor according to Fig. 7, and which again has been represented in Fig. 11.

If the line of the brushes makes an angle A with the axis of the main winding and $A\ T_{max}$ represents the total magnetomotive force yielded by this winding, then we can resolve $A\ T_{max}$ into two components, one $A\ T_{a\text{-}m}$ being along the line of the brushes and $A\ T_{field}$ at right angles to this line. By shifting the brushes, we increase one of the components and simultaneously decrease the other. There are two positions in which the torque vanishes, that is, for A equals zero, in which case the field is zero, and for A equals 90 degs., in which case the armature current is zero. In case A equals 20 to 30 degs., the torque will be maximum.

Digitized by Google

Since the motor, according to Figs. 7 and 11, is very sensitive in regard to the position of the brushes, an arrangement has been made for reducing the effect resulting from a certain displacement of the brushes.

Fig. 12 represents this arrangement for the Deri motor, which has four brushes for two poles, two of which are stationary (*Bs*1 and *Bs*2) and two movable (*Bm*1 and *Bm*2). Assuming that the position in which the line of the brushes *Bm*1, *Bm*2 falls along the line of the brushes, *Bs*1, *Bs*2 corresponds to a certain speed, then after the brushes have been shifted over an angle 2*A*, according to Fig. 12, the axis of the armature will have been shifted over an angle 1*A* only.

LaTour has proposed a scheme also with four brushes for two poles, which, however, in this case are moved simultaneously, keeping the same relative position to each other. In this case, a part of the armature, *i.e.*, the conductors between the brushes, *Bs*1 and *Bm*2 are always ineffective in regard to generation of e.m.f., whereas with the Deri motor, this part is ineffective at certain speeds only. The advantage of the arrangement according to LaTour is that the brushes are standing in such a position that less trouble is caused by induction of an e.m.f., which affects the commutation of the short circuited coils under the brushes.

* The importance of the brush shifting motor warrants further consideration and we may consider the theory of operation in a different manner. Let us suppose the rotor winding replaced by two equivalent windings, which are in space quadrature, and which, while independent of each other magnetically, must be regarded as electrically connected in series. (See Fig. 13.)

The magnetic axis of one winding is coincident with the axis of the stator poles, while the axis of the other winding is in space quadrature with the stator poles. The first winding alone is subject to the inductive action of the stator flux and plays the part of the secondary of a transformer, of which the stator winding forms the primary. This winding will be called the transformer winding—the secondary winding may be termed the quadrature winding. Any flux produced by the current in the quadrature winding will be in time phase with the current in the transformer winding and will produce accelerating torque at the rotor.

* See the *Electrician*, London, January 3, 1908.

Digitized by Google

Figs. 14, 15 and 16 indicate three positions of the brushes and show the equivalent connection for the transformer and quadrature windings on the motor. Both when the axes are together and when they are separated by 180 space degrees, the torque is zero. In the former case, the transformer effect is zero, while in the latter case, there is no quadrature effect.

Under speed conditions, there are produced two e.m.fs., which affect the value of the secondary current, and therefore, alter the torque, which for each position of the brushes varies directly with the square of the current in the armature. One e.m.f. appears at the transformer axis and the other at the quadrature axis—the former is proportional to the product of the speed and the quadrature flux, and the latter varies directly with the product of the speed and the transformer flux, these two e.m.fs. have such values and time-place position as to tend to decrease the armature current with increase of speed.

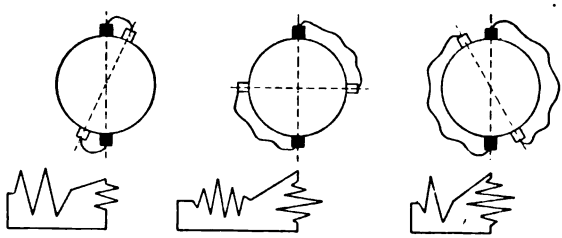


FIG. 14 FIG. 15 FIG. 16

With constant primary voltage at any given speed, the current and torque can be varied over a wide range by merely shifting the brushes, as explained above.

It will be seen from the above that the machine possesses the speed, current and speed torque characteristics of the direct-current series motor.

In general it can be said that a motor laid out for brush shift has to be built of larger size than one with stationary brushes. Considering that the ratio of the cost of the control apparatus to the cost of the motor is, with certain exceptions, smaller in proportion for large motors than for smaller ones, it would appear that the necessity of increasing the size of the motor—in case brush shifting be used, for small motor applications, less increase in the total cost of the equipment than by using controllers and transformers.

Digitized by Google

MULTISPEED*

The induction motor as usually spoken of is primarily a constant speed motor. Where variable speed is required a motor with collector rings is used, the speed variation being produced by varying the amount of resistance in the secondary circuit.

Many times it so happens that two or three speeds will be satisfactory for the operation of the machinery and these speeds must be independent of the load. Under such conditions, multispeed motors can frequently be used.

In these motors the different synchronous speeds are produced by changing the number of poles in the magnetic circuit. Each of these speeds is fixed, if no resistance is used in the secondary circuit. With multispeed motors, as with single speed motors, resistance may be used in the secondary circuit for varying the speed.

A change in the number of poles may be produced in any one of the following ways:

1. By the use of single magnetic and electric circuits, changing the number of poles by regrouping the coils.
2. By the use of single magnetic circuits and independent electric circuits.
3. By means of separate magnetic and electric circuits.

1. *Single Magnetic and Electric Circuits.* Where two speeds only are required and those of ratio 2:1, the motor with single magnetic and electric circuit is admirably adapted, due to economical use of material, all of which is active at both speeds and simplicity of pole changing, six leads only being required for two or three-phase motor. For any ratios other than 2:1, the switching and wiring becomes more or less complicated, the ordinary three-phase winding requiring 33 leads and two-phase requiring 16 leads.

2. *Single Magnetic and Independent Electric Circuits.* Where speed ratios other than 2:1 are required it is much more practicable to use independent electric circuits. These motors, having independent windings, have three leads for each speed in the stator for three-phase motors and four for two-phase motors.

Theoretically, it is possible to obtain a number of different speeds, but is usually impracticable to use more than two windings.

* See TRANSACTIONS A. I. E. E., 1908. Articles by H. G. Reist and H. Maxwell and H. C. Specht.

Digitized by Google

Obviously, it is possible to combine 1 and 2, thereby obtaining four speeds requiring twelve leads for a two or three-phase motor.

In a motor with 2:1 speed ratio, using single magnetic and electric circuits, the material is used to the best advantage when the output at low speed is approximately one half of that at the high speed. It is possible, however, to vary the output at the low speed over a wide range depending upon the connections employed in the primary.

Speed	Connection	Approx. max. output
(1) 100	2 circuit delta	100
50	Y delta	11
(2) 100	2 circuit Y	100
50	1 circuit Y	22
(3) 100	2 circuit Y	100
50	1 circuit delta	66
(4) 100	1 circuit delta	100
50	2 circuit Y	117
(5) 100	1 circuit Y	100
50	2 circuit Y	350
(6) 100	Y delta	100
50	2 circuit delta	700

From this table it will be seen that there is a wide range of choice of outputs. These combinations are often valuable in order to maintain good efficiency and power factor at the desired loads.

Motors of this type are adapted for driving machine tools, printing presses (certain cases only), pumps, blowers, etc.

3. *Separate Magnetic and Electric Circuits, (Cascade).* Multi-speed motors as referred to under (1) and (2) become objectionable in the larger sizes, especially where it is desirable to change speeds frequently, or it is objectionable to open the primary circuit.

Where two- or three-speed motors of very low speed are required, two motors operating in concatenation should be used since the ratio of the diameter to the length of the changeable pole motor becomes very great, resulting in excessively heavy construction to secure the necessary rigidity, and high costs. With the concatenated set, one motor operates alone to obtain either of the high speeds and the two motors operating in concatenation for the low speed. These sets are also designed for operation at variable speed in addition to the fixed speeds.

For the concatenated connection, they are generally of the

Digitized by Google

polar wound type, although the last motor of the set may be of the squirrel cage construction. The rotors are usually mounted on the same shaft, making a two unit set. The primary of the first motor is connected to the source of supply at its secondary to the primary of the second motor, as shown in Fig. 17.

Considering two single-speed motors to comprise the set, the maximum number of speeds (not including resistance steps) obtainable is four, two of which consist of either motor with its primary connected to the line and secondary short circuited, the other two being obtained by direct and differential concatenation.

Two motors are connected in direct concatenation, if they have a tendency to start in the same direction and differential concatenation, if they tend to start in opposite directions.

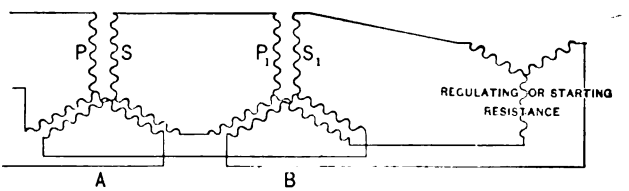


FIG. 17

Synchronous speed of motors in concatenation is as follows:

$$\text{Speed} = \frac{\text{Cycles} \times 120}{P_1 \pm P_2}$$

P_1 = poles motor A.

P_2 = poles motor B.

Plus sign to be used when motors are in direct concatenation and minus when in differential concatenation.

Where more speeds are required, it is possible to use three motors, but the cost becomes prohibitive and switching complicated. A much better and cheaper proposition is to use one or two, two-speed motors, depending on the number of speeds required.

The operation and control of the cascade set is simple, especially for direct concatenation.

With the multispeed (pole changing) motor in changing from one speed to the other, it is necessary to open the primary circuit; this may be obviated in the cascade sets by introducing

Digitized by Google

resistance in the leads between motors *A* and *B*, this resistance to be cut in or out step by step, in changing from one speed to the other. Fig. 18.

In the concatenated motor, speed reduces somewhat as follows: With the polar wound single-speed motor, the reduction in speed is accomplished by reduction in efficiency, the power factor remaining constant. In the concatenated motor, the efficiency will remain approximately constant, but the power factor goes down as the speed is decreased. This low power factor is due to the fact that the motors are underloaded when run in concatenation, as compared with normal rating, as individual motors.

Recently there has been brought out in England, the Hunt or internal concatenated motor. The machine is a modified form of the "cascade" motor, having two magnetic field systems, superimposed upon one another in the same core body.

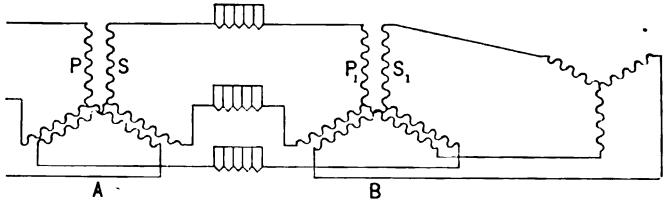


FIG. 18

The second field has its origin in the rotor and consequently induces secondary currents in the stator windings. (See Fig. 19).

The motor can be laid out for cascade speeds of 12, 18, 24 poles, *i.e.*, numbers divisible by six, the lowest number of poles being 12. A motor having a smaller number of poles is not satisfactory, as the resultant magnetic field is not symmetrical.

Considering an eight-pole stator winding with taps brought out in such places that the winding can be made responsive to a four pole field. The motor has a winding which gives the effect of an eight-pole and four-pole winding in series. The motor can operate either in cascade with a speed corresponding to 12 poles or as an eight-pole motor. In order to obtain three effective speeds, a change over switch is necessary in the stator circuit. This enables the connections to be changed so that the primary currents may produce either an eight-pole or a four-pole magnetic field.

Digitized by Google

The arrangement of the windings are such that if the slip rings are short circuited, the currents induced in the rotor give only one number of poles, and the machine under these conditions behaves exactly like an ordinary slip ring motor.

When the slip rings are open circuited, a small number of the rotor conductors become inoperative and the currents in the rotors then produce two number of poles, the second of which acts upon the stator and causes the motor to run at cascade speed.

Although no figures are available, it appears possible with Mr.

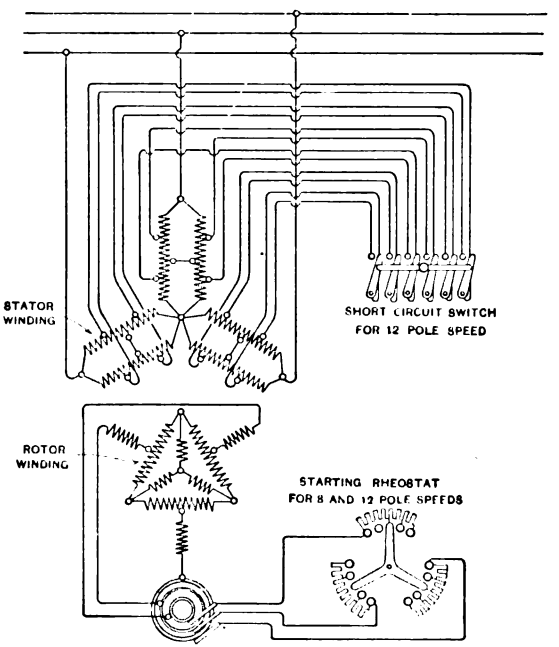


FIG. 19.—Hunts 2-speed motor for continuous service

Hunt's methods to design a cheaper two-speed motor than the ordinary collector ring type with two primary and two secondary windings. On account of the whole winding being used all the time, this type of motor ought to have a better efficiency and power factor than a double-wound motor.

With this construction, it seems possible to obtain a motor of smaller size and cost with better constants than a two-speed collector ring motor or cascade set. Continuous acceleration is possible by means of rheostats without opening the main circuit.

Digitized by Google

Frequency Changers

For adjustable speed work, where a large number of speeds are not required and frequent changes not necessary, a simple method may be used, *i.e.*, by using a frequency changer set, consisting of an alternating-current motor and required number of generators for the various frequencies.

This system is objectionable on account of high cost and large speed steps. It is also impracticable to change speeds while running. The efficiency of the combined outfit is comparatively low.

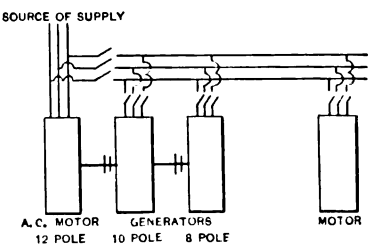


Fig. 20

Where direct current is available, a simple method may be employed affording easy methods of control while running. Speed changes are obtained by changing the primary frequency applied to the driving motor operating as an ordinary induction motor.

By far the simplest method is to use a direct-current motor driving an alternator and by varying the speed, the frequency and voltage delivered by the alternator is in direct proportion to variations in speed.

In this case it is necessary for the units of the set to be of sufficient capacity to take care of driving motor *C*.

Another method of accomplishing the same result, is to use an

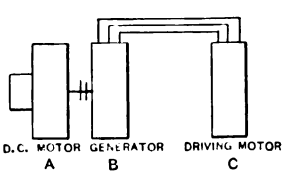


Fig. 21

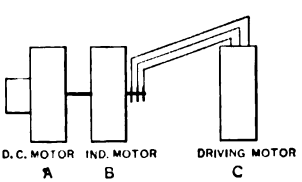


Fig. 22

induction motor in place of generator *B* and using the secondary of motor *B*, as the source of supply for motor *C*. (See Fig. 22.)

The primary of the induction motor *B* is connected to the alternating current source of supply and the speed of the set is controlled by the direct-current motor. The secondary of motor *B* supplies power to the motor *C* operating at variable speeds.

When the frequency changer set is running at a speed corresponding to the synchronous speed of motor *B*, the frequency

Digitized by Google

in the motor is zero. The frequency at any other speed may be determined as follows:

$$C = C_1 \left(\frac{N - N_1}{N} \right)$$

C = frequency in rotor B.
C_1 = frequency source of power motor B.
N = synchronous speed motor B.
N_1 = speed of frequency changer set.

The minus sign in the above formula becomes plus when the set is running in the opposite direction to the normal operation of motor B.

The voltage in the rotor B is the ratio of primary turns to secondary turns (neglecting losses in air gap), and varies directly as the frequency.

It is obvious that it can only be used for constant torque work with limited speed range, otherwise the costs which are already high become prohibitive. The direct-current motor A supplies only a fraction of the power supplied the motor C, depending upon the speed range.

Motor B must be of the same capacity as C. Motor A runs as a generator when the frequency set runs in the same direction as normal operation of motor B, as motor when running in the opposite direction.

A number of systems have been proposed involving more or less complicated and expensive features.

Another quite simple system has been proposed—differing from those previously referred to—in which the primary of the driving motor is connected to the power circuit of constant frequency, speed control being obtained by impressing different frequencies on the secondary winding of the motor. By supplying to the secondary of the driving motor, a variable frequency, and to the primary a constant frequency, the motor must run at speeds corresponding to the sum or difference of the primary and secondary frequencies. It is well known that the speed of an induction motor corresponds to the difference of primary and secondary frequencies. By supplying the secondary with a variable frequency, speed changes may be obtained corresponding to the resultant of two frequencies in the rotor, the one produced by the rotating field and the other from some outside source.

Digitized by Google

There are, however, a number of cases where a multispeed motor is not satisfactory since it does not give sufficient number of steps and there has been felt a real need for an alternating-current motor with shunt characteristics. In fact, the matter is very important, since the absence of such a motor often necessitates the application of direct-current apparatus, even if only a few adjustable speed motors are required and all other conditions would warrant the use of polyphase or single-phase alternating-current motors. Hence, the problem is not to obtain a motor which is better and more efficient than the direct-current adjustable speed motor, but the first step and at present, the most important, is to obtain an adjustable speed motor, no matter whether it be a little inferior in characteristics to a direct-current motor, in order to help us out in the above case and all schemes which are to be described in the following, have to be judged in this light.

Considerable work has already been done in this country for

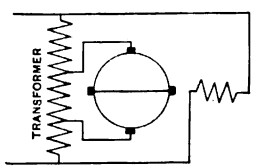


FIG. 23

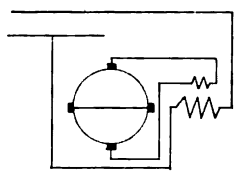


FIG. 24

the adjustable speed, single-phase motor.* In order to outline the theory of this interesting type of motor, we may refer to the compensating repulsion motor as covered by Fig. 8, and see what is happening when this motor is running at synchronous speed. We assume the motor has a cylindrical core without salient poles, in which case the mutual inductive impedance is equal, in all directions. Neglecting the self inductive reactance of both circuits, it is apparent that at synchronism the current flowing between the exciting brushes has to be equal and 90 degs. displaced in time phase to the magnetizing current flowing in the compensating windings (reduced to the armature circuit). Otherwise the requirement would not be fulfilled that the e.m.f. of transformation be balanced by the e.m.f. of rotation.

In the circuit between the field brushes, a similar condition

* See articles TRANSACTIONS A. I. E. E., 1909, Vol. XXVIII, page 475 by F. Creedy, 1909 by E. F. Alexanderson, Vol. XXVIII, page 511 and paper by W. A. Layman, May 1911, National Electric Light Association.

Digitized by Google

exists. The current flowing from brush to brush induces a reactive voltage, which at synchronous speed is completely balanced by the e.m.f. induced by a rotation through the cross flux interlinked with the compensating windings. Hence, at synchronism, in order to obtain a current which will be in time phase with the energy current, we have merely to apply a voltage to the brushes of the same time phase as the voltage applied to the energy circuit and which has only to compensate the IR drop in the exciting armature circuit.

This has been done in Fig. 23 by means of a transformer. The stator proper can also be used as a transformer for supplying this voltage, if a second winding has been provided on the same, as shown in Fig. 24, or by equipping the compensating winding with suitable taps, so as to use it as an auto transformer. In this way we have obtained a shunt motor which will run at constant speed. It can be started as a series motor in the connection shown in Fig. 8.

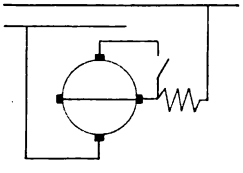


FIG. 25

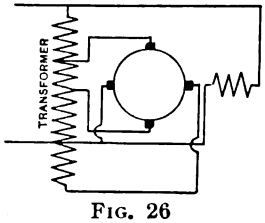


FIG. 26

Fig. 25 represents a compound motor. If the switch is opened, then only half the armature works as field winding, and in this way the motor can be started as a series motor. When up to speed, the switch can be closed and the other half of the armature will receive shunt excitation.

In order to make out of the motor, according to Fig. 23, one which shall give equally good characteristics, at speeds differing from synchronous speed, we have to open the short circuit of the energy brushes and apply voltage to the same. This has been shown diagramatically in Fig. 26.

Suppose we apply to the energy brushes a voltage which is equal and in time phase with the voltage formerly induced between the short circuited brushes by transformation. If we further increase the current between the exciting brushes $41\frac{1}{2}$ per cent and also the speed $41\frac{1}{2}$ per cent, then it is clear that the e.m.f. of rotation induced between the energy brushes, which is proportional to both the field strength and the speed,

Digitized by Google

will be increased 100 per cent, and will balance the voltage of the energy circuit, which is the sum of the applied and the voltage induced by transformation. But also the voltage in the exciting circuit will be balanced. The reactive voltage being increased over 41½ per cent, due to the increase of current and the voltage induced by rotation also being increased over 41½ per cent, since the speed has only been changed and not the field interlinked with the compensating winding, which induces the e.m.f. of rotation between these brushes. By thus properly choosing the voltage applied to the two different sets of brushes, it is possible to obtain different speeds, both above and below synchronism. Of course, it is again possible to omit the transformer by using the stator for this purpose.

Analytically, the conditions for equilibrium can be investigated in the following manner.

Let:

$\dot{E}_{fa}$ = voltage applied to field brushes.
$\dot{E}_{ft}$ = voltage induced by transformation between the field brushes.
$\dot{E}_{fr}$ = voltage induced by rotation between the field brushes.
$\dot{I}_f$ = current and field circuit.
$\dot{E}_{ea} = x\ \dot{E}_{et}$ = voltage applied to energy brushes.
$\dot{E}_{et}$ = voltage induced by transformation between the energy brushes.
$\dot{E}_{er}$ = voltage induced by rotation between energy brushes.
$\dot{I}_m$ = magnetizing current in the compensating winding.
n = speed.
n_0 = synchronous speed.
Z = mutual inductive impedance.

Then at standstill we have in the field circuit, e.m.f. consumed by mutual inductive impedance:

$$\dot{E}_{fa} = \dot{I}_f Z$$

And for the energy circuit we have e.m.f. consumed by mutual inductive impedance:

$$\dot{E}_{et} = \dot{I}_m Z$$

At a speed n, we have in the energy circuit to meet the requirement that the voltage applied to the brushes has to be equal

Digitized by Google

to the voltage consumed by mutual inductive impedance and by the e.m.f. of rotation. Hence,

$$\dot{E}_{ea} = \dot{I}_m Z + j\frac{n}{n_0} \dot{I}_f Z$$

If further

$$\dot{E}_{ea} = \dot{E}_{ei}$$

Then since

$$\dot{E}_{ei} = \dot{I}_m Z,$$

we have

$$x \dot{I}_m Z = \dot{I}_m Z + j \frac{n}{n_0} \dot{I}_f Z$$

This is only possible if

$$\dot{I}_f = j\, y\, \dot{I}_m$$

or

$$x = 1 - y \frac{n}{n_0}$$

For the field circuit we have, that the applied voltage has to be equal to the sum of the voltages consumed by the e.m.fs. of transformation and rotation, *i.e.*

$$\dot{E}_{fa} = \dot{I}_f Z - j \frac{n}{n_0} \dot{I}_m Z,$$

or since

$$\dot{I}_f = j\, y\, \dot{I}_m,$$

we have

$$\dot{E}_{fa} = \dot{I}_f Z \left(1 - \frac{n}{n_0} y\right)$$

Digitized by Google

Neglecting the resistance of the field winding the requirements for the equilibrium of the e.m.f. in the field winding should be

$$\dot{E}_{fa} = 0$$

or

$$y = -\frac{n}{n_0}$$

Substituted in

$$x = 1 - y\,\frac{n}{n_0}$$

gives

$$x = 1 - \left(\frac{n}{n_0}\right)^2$$

or

$$\dot{E}_{ea} = \left\{1 - \left(\frac{n}{n_0}\right)^2\right\}\ \dot{E}_{et}$$

For $n = 1415$
$n_0 = 1000$
We would find

$$\dot{E}_{ea} = 1 - \left\{\left(\frac{1415}{1000}\right)^2\right\}\ \dot{E}_{et}$$

or

$$\dot{E}_{ea} = \dot{E}_{et},$$

and

$$\dot{I}_f = j\,\frac{1415}{1000}\,\dot{I}_m = j\ 1.415\ \dot{I}_m$$

We thus arrive at the same result as above.*

* See *Electro Technische Zeitschrift* 1908, page 588 and page 857. [Eichberg.]

Digitized by Google

The above outlined method is a combination of armature and field control. With armature control carried out in a different way, the same result can be obtained. Let us suppose we apply to the compensating winding, 70 per cent of the voltage originally applied to the same, and impress on the energy brushes this very same voltage. Then apart from magnetic saturation conditions, the cross flux interlinked with the exciting current of the compensating winding will be reduced to 70 per cent of its original

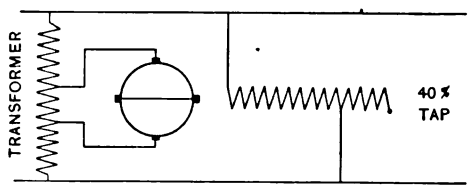


FIG. 27

value. If now again the speed increases 41½ per cent, then the conditions for equilibrium have been obtained. The current in the exciting windings will be unchanged since the e.m.f. of rotation is the same as before, the speed being increased 41½ per cent and the field strength being reduced to 70 per cent of its original value. Neither in this case do we need a transformer if we provide the stator with steps.

In Fig. 27 a diagram of connections is demonstrated for a

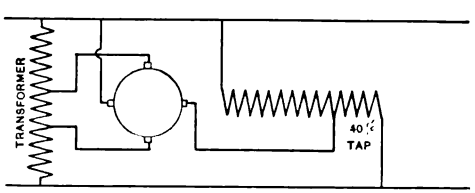


FIG. 28

motor, which, in this connection will run at synchronous speed and 40 per cent above synchronous speed when connected according to Fig. 28. For matter of simplicity it has been assumed that both the armature and compensating winding have the same number of effective turns, in the connection of Fig. 27.

In case we use armature control without providing special

Digitized by Google

means for balancing the exciting circuit, also, speed regulation can be obtained. Then, however, the current in the exciting winding will be larger, due to a wattless component which does not contribute to the torque.

As long as this wattless component does not become excessive, so as to cause sparking, its presence is not objectionable.

Another interesting type of motor has been described by Mr. Alexanderson in the paper referred to above. With one of the two described motors, he uses field control and he has developed his method in such a way that it directly can be applied to the compensated repulsion motor. Instead of obtaining the equilibrium in the field and energy circuits by the methods described above, he makes use of the fact that the voltage appearing at the terminals of the exciting winding arranged on the stator in quadrature to the compensating winding is 90 degs. out of time phase with the line voltage and consequently in time phase with the e.m.f. induced between the field brushes by rotation through the cross flux. This voltage, after having been stepped up or down by means of a regulating transformer, is introduced between the field brushes and thus regulating the current in the field winding, the speed can be varied.

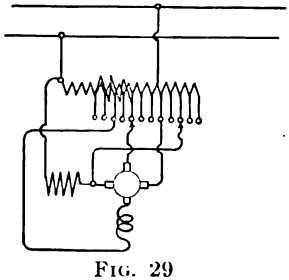


FIG. 29

The variable speed motor described by Mr. Layman in his paper is in principle a combination of the different types which have been described above and for further reference we may refer to his paper.

Of course, in case of a motor with series characteristics it is also possible to impress voltage on the energy brushes and obtain, in this way, speed regulation. The methods follow directly from what has been explained in regard to the shunt motor.

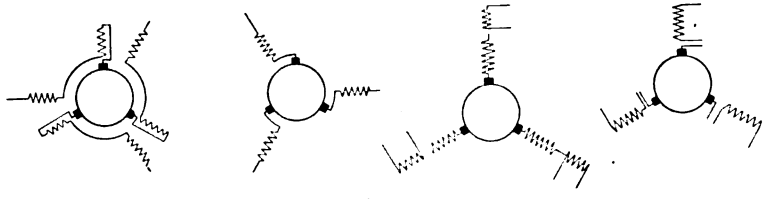
POLYPHASE COMMUTATOR MACHINES

The polyphase commutator motor has a fixed winding consisting of a number of coil groups, corresponding with the number of phases, just like the stator of an ordinary induction motor, these groups of coils being displaced in space by an angle corresponding to the displacement of the several phases from one another; thus in a three-phase winding, they are separated by 120 deg. The revolving part of the motor is wound like a

Digitized by Google

continuous current machine and provided with a commutator. The field of a polyphase commutator motor is produced by the exciting winding, which is fed by a current or pressure. If the energy current of a motor is used as exciting current, the rotary field produced will not be constant, but will depend on the output of the motor. Thus, if the exciting winding E, Fig. 30 is connected in series with the energy winding the motor will have series characteristics, the speed being a function of the torque. On the other hand, if the exciting winding E is fed from a constant voltage, Fig. 32, the field will be constant, independent of the load. This motor possesses a shunt characteristic and runs at approximately constant speed. In addition to these, combinations can also be made to give compound characteristics.

Figs. 30 to 33 show arrangements of winding of three-phase motor.



Series motor with separate exciting winding — FIG. 30

Series motor with combined exciting and compensating winding — FIG. 31

Shunt motor with separate exciting winding — FIG. 32

Shunt motor combined exciting and compensating winding — FIG. 33

Three-phase commutator motors

The difficulty of regulating the speed of induction motors hitherto was that no means were known whereby the low frequency of the rotor currents could be transformed to that of the mains. It was only the knowledge that the commutator always transformed the slip frequency to that of the motor field, thus to that of the supply—that made this possible, for, since the commutator can be directly connected to the network, energy can be given or taken, according to the conditions.

It has been shown that the three-phase commutator motor of moderate size and designed for moderate frequencies has been employed extensively in such cases where speed variation over a wide range and shunt characteristics are required. The design of the three-phase commutator motor meets, however, with difficulties if larger sizes or higher frequencies are required. The commutation becomes poor and costs high.

Digitized by Google

Kraemer System*

Previous to the introduction of the commutator motor, it was necessary to sacrifice efficiency for regulation, the imperfect method of inserting resistance in the rotor circuit being used.

It was a happy thought that led Kraemer to supply only that power to the commutator motor which would otherwise be consumed in the rotor resistances. (See Fig. 34.)

In this system the commutator machine is direct connected to the shaft of the main motor and the energy furnished by the slip rings of the main motor is returned as mechanical energy to the shaft, instead of being absorbed in resistance. This arrangement is of advantage in cases where a constant h.p. motor is required because the torque of the machine, which is proportional to the slip, is added to the torque of the main motor.

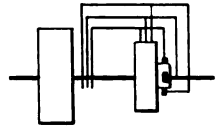


Fig. 34

The slip energy of the induction motor can also be recovered by the application of a rotary converter. This equipment has the disadvantage of greater complication and also special source of direct current. (See Fig. 35).

Referring to Fig. 35, the slip rings of the main motor are connected to a rotary converter, the direct current side of which

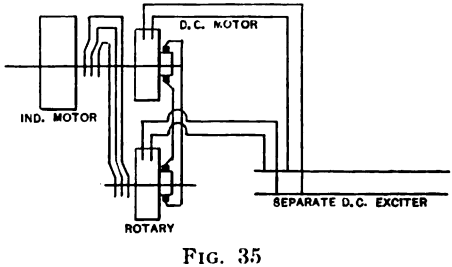


Fig. 35

feeds a direct-current shunt motor, the latter being connected mechanically to the main motor shaft. The speed is regulated by varying the field of the direct-current motor. When the resistance is cut out, the armature voltage and the direct current voltage of the converter will increase. Necessarily the alternating current voltage will increase also, thus the speed of the main motor will decrease. For wide ranges of regulation, this system is particularly applicable, as the design of the rotary

* See the *Electrician* (London), August, 1910.

Digitized by Google

converter is practically independent of the speed reduction required.

SCHERBIUZ

Speed regulation has been worked out in a slightly different manner by Scherbius, employing a polyphase commutator motor.

With reference to Fig. 36, a three-phase commutator motor (regulating motor) is connected to the slip rings of an induction motor. The regulating motor drives a generator which again delivers electrical energy to the line, or a regulating motor is direct connected or belted to the main load. Whether the slip energy of a main motor should be recovered as electrical or mechanical energy depends upon the nature and condition of the motor application. By adjusting the excitation of the regulating motors, speed variation of the main motor is obtained, as the slip of an induction motor is proportional to the secondary voltage. The speed of the regulating motor remains constant

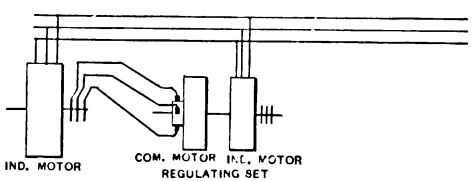


FIG. 36

between no load and full load. The speed depends upon the excitation only, the armature voltage being practically the same as the rotor voltage of the induction motor. Ordinarily the commutator motor has shunt windings. Where a flywheel is used, series or compound windings are used; the speed will then drop over a certain adjustable range and use be made of the kinetic energy of the flywheel. It should be mentioned that by reversing the direction of the excitation, the regulation can be extended over synchronous speed (special exciter required) the regulating motor becoming a generator and delivering the slip energy instead of receiving it. The commutator motor can be designed so that it delivers wattless current and thus improves the power factor of the whole installation.

The use of an independent regulating set has the advantage that the commutator machine can be designed for an economical speed and in this way becomes a cheaper proposition.

Very considerable progress has been made of the use of the

Digitized by Google

alternating current commutator motor in Europe. The brush shifting motor as originally developed was a single-phase motor and is now being built three-phase. The simplest arrangement for three-phase operation is to use two single-phase motors using the T connection.

Various modifications of the Kraemer and Scherbius systems have been used showing excellent results as to regulation and economy of operation.

Digitized by Google

DISCUSSION ON "TRANSMISSION SYSTEMS OF THE WESTERN POWER CO.," "THE SOUTHERN POWER CO.," "THE GREAT FALLS POWER CO.," and "THE SOUTHERN COLORADO POWER CO." CHICAGO, JUNE 29, 1911. (SEE PROCEEDINGS FOR JULY AND AUGUST, 1911.)

(Subject to final revision for the Transactions.)

Percy H. Thomas: The High Tension Transmission Committee this year wish to give opportunity for the consideration of matters pertaining to the design and operation of extra high tension transmission systems, that is, systems of 80,000 volts or higher. As we have a number of these systems in actual operation, the time appears ripe for a first discussion or interchange of ideas on this subject. The Committee during the early part of the year, sent out a list of questions to some seven plants, which are operating at such voltages, with a request for brief categorical answers to the questions which had been prepared. The Committee has received the four communications under discussion. The original questions were as follows:

1. Do you operate with a grounded neutral? If so with or without resistance, with how much and of what type.
2. Do you use overhead ground wires, if so how many and how spaced and how frequently grounded?
3. Standard span, length, material of conductor, spacing of conductors, clearance from the earth, etc. Also, data on special spans of interest.
4. Occurrences of lightning, how frequent, its effects on the system.
5. What is the charging current of your line? Give if possible accurate data as to length of line, size and spacing of conductors, frequency, etc., at the time of the making of the measurement. Note any peculiarity in charging current.
6. Experience with insulators, electrical and mechanical, swinging of conductors with suspension insulators.
7. Experience with high tension switches, opening charging current and load current, type of switch used.
8. Supply and control of charging current; is there synchronous receiving apparatus on line? Minimum size of generator and transformer units. Actual number and capacity of generators connected to the system.
9. Experience with outlets and terminals.
10. Experience with electrolytic and other high tension arresters.
11. Experience with wind and sleet.
12. Experience with corona effects.
13. Experience with telephone communication and disturbance thereof.
14. Regulation.
15. Notes on towers, type, foundations, corrosion, etc.
16. How long has your system been operating at its present voltage?

I will take a few minutes to bring out some of the matters which appear to be of greatest interest in these reports, and make some comments based on other data. The general conclusion from these communications seems to be that the operation of 80,000 and 100,000 volt systems is satisfactory, not that operation is perfect in all cases, but that it is as satisfactory as operation at lower voltages.

It appears from the actual experiences of these plants that some of them are very close to the practical corona limit. Although no plant is actually handicapped in its operation by

Digitized by Google

corona loss, there is good evidence that the voltage could not be greatly raised in these cases without a serious loss. We can now figure quite closely, however, in future plants on the results we may expect to get.

The feature of greatest interest is the operation and design of the constructions utilizing conductors hung on suspended insulators, conductors which are not mechanically rigidly fixed to the tower at the insulator, as with the pin type. You will all recognize that wires suspended in this manner become what may be called an elastic medium, that is, if there is a displacement in the wire at any tower, lengthwise or sideways, there is a returning force, which gives the effect of elasticity to the wires. The wires also have inertia. We have, then, elasticity and inertia, which are two quantities necessary to produce wave motion in any other mechanical device. Elasticity and inertia correspond to capacity and inductance, respectively, in transmission circuits.

We must then consider whether we are to experience in suspended conductors the sort of waves, that we have found so troublesome in alternating circuits. Contrary to the first expectations of the engineers laying out suspended inductors, it turns out that trouble from these waves is to be apprehended in some cases. Some of our plants it is true have operated without a suspicion of trouble from mechanical waves, or mechanical motions of suspended conductors, but others have had difficulties, and it becomes of importance to outline and set forth and study, especially study, what are the conditions which will magnify the effects of mechanical waves and which will restrain them; also under what conditions they may be expected to be serious.

The laws of wave motion are well worked out in other directions. They may be briefly summarized by saying that a wave in any system, passing along on a uniform conductor will tend to maintain its velocity and its amplitude, except for friction losses, until it strikes a reflecting point or dividing point. If it strikes a point of total reflection that is a rigid support, the wave will be returned in the reverse direction without losing strength by the reflection, but at the reflecting point there is a strain of double amplitude. With a recurrent source of waves and a reflecting point, there will be outcoming and returning waves, continually passing and re-passing, and where they pass they make stationary waves of double magnitude. Any particular suspended transmission conductor will have a definite period of swing. It swings like a pendulum. The velocity of these waves passing along will be relatively small.

When any point of the transmission line is thrown to one side and released, it produces a wave, or if it is thrown and suspended in the thrown position, the first act of throwing sends a wave along the line.

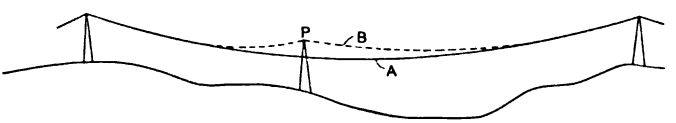
We must consider the matter of resonance. If for any cause

Digitized by Google

we have a portion of a line swinging in a definite period, waves will be sent along the line, and if they are reflected and return in the original point, there may be a building up of the amplitude of the swing, as with a coil and condenser, or any other form of resonance. This condition is not likely to occur very often in suspended conductors. The independent, constant, source of energy which will maintain an exciting oscillation is likely to be absent. There might be a case where a line of heavy mass has been set swinging, and some line of lesser mass is connected to it, and in that case the stored energy in the swinging of the heavier mass may serve to send out a number of impulses into the branch circuit.

The thing that is likely to give difficulty in a suspended conductor in practical operation is the amplitude of the swing. If the swing is great enough, the conductor may come near enough to its support to permit a spark to pass. This has occurred in many instances in the last two or three years.

What is it that determines the amplitude of the swing? In the first place, the amplitude is restrained by the fact that as the wire swings to the side it is lifted and gravity tends to return it—if the suspending connection, the chain of insulators is short, the length of the pendulum is short, and the conductor rapidly rise



against gravity as it swings to the side, and the motion becomes a short motion. If the length of the supporting chain is long, however, the amplitude of the swing in feet will be greater. The amplitude in angular degrees may be the same, but the amplitude in feet will be greater. Thus, if instead of using the necessary four suspension insulators, in a certain case, a big margin of safety is demanded and seven or eight insulators are used, there would result a much wider amplitude of swing from the added disks with possibly disastrous results. In avoiding one trouble there would be danger of getting into another.

The length of the span will, of course, have a good deal to do with the amplitude, because the sag will be greater on long spans. The greater the sag, from the same reasoning, the greater will be the amplitude of the side swing in the center of the span; that is, if you take a small conductor, and to keep within its strength you use a very great sag, that sag exposes the line to a much wider amplitude of swing for a given disturbing impulse than a line with a lesser sag, and that is a fact to be borne carefully in mind in design work. This condition may in some cases be the limiting factor in determining the length of span with small wires.

There is another difficulty, which is shown in the accompanying sketch. Suppose the custom of the country would naturally give

Digitized by Google

us a very long span as shown at *A* and suppose this is a little too long and a tower is placed at the point *P* and make the contour like the line *B*. If it were not for the central support, the tendency would be for the line to have a long swing at the point *P*, corresponding to the long span, because it has a large sag from the point of support. The effect of the tower at the point *P* is to relieve the long span of only a small portion of its weight. That is if the line starts to swing at the centre the weight supported by the tower at *P* has very little restraining force and the energy of the main portion of the span may carry the conductor up against the cross arm. This is a real danger and a matter which is very easily overlooked in laying out a line. Be very sure that there is a sufficient weight hanging on the intermediate insulator so that as the wire rises at this insulator due to the restraint of the short link, a sufficient weight is affected so that there is a big natural returning force.

There is another situation with suspended conductors which tends to give trouble. Assume a two-circuit line, with two overhead ground wires, the ground wires being steel and the line conductors aluminum. If now swinging is set up the steel and the aluminum will not swing in the same time period and clearance must be provided for the most unfavorable positions of various conductors.

Ordinarily in systems of suspended conductors there is very little swinging, and what occurs is apt to be very slow and steady, but there do come conditions in which the oscillations are not uniform and in which they are very severe. Wind is, of course, the chief exciting cause. It is not, however, necessarily the only exciting cause. There is the possible effect, of current on the swinging of suspended conductors. With a short circuit on two parallel wires of a circuit, the wires would tend to spread. If you have two loops, one on each side of a system, situated parallel a short circuit may tend to spread both wires and bring together the two inside wires or throw them against some other wire. The spreading force depends on the square of the current and is thus not very large with very high tension systems, except when of enormous capacity. To show what may occur in some instances, however, I will tell of one instance, which occurred on a 10,000-volt plant. There were two wires something like 20 or 30 in. apart with spans of about 150 feet. A short circuit occurred somewhere on this line, a short way from the power house, and the force of propulsion, due to the short circuit current, was sufficiently great to separate the wires under great tension, storing considerable energy in the elasticity of the wire. The action of a circuit breaker cutting off the current allowed these wires to come together until they wrapped around each other, and stayed permanently there, and a good deal of force was required to unwind them. A force of that magnitude, in most of our present suspended conductors would make trouble, but, of course, on 50,000 or 100,000-volt systems, no such currents

Digitized by Google

are obtainable, as are met with near a large power house on a 10,000-volt circuit.

There is still another point which must be borne in mind in connection with suspended conductors. If we have a short span and a long span adjacent, and these two spans are set with the suspension link vertical on a warm day, in cold weather, these spans are much tighter, and the stresses will no longer be equal on account of the difference in lengths of the spans. The wire will thus pull toward the shorter span as the temperature gets lower. If the spans are long this may pull the insulator far out of plumb, reducing somewhat the clearance, and throwing twisting strains on the cross arm. That is one of the objections to having a long span and a short span closely adjacent.

Mr. Hendricks, I believe, suggested providing for slipping of a clamp on the conductor, changing its location as between hot weather and cold weather. That might be a practicable thing to do.

There are many other interesting points brought out in these communications, which I will not take the time to mention. The maximum span is about 3,000 feet. Telephone lines are successfully operated through split inductance. The matter of tower foundations is called to our attention—do not sit in the office and prescribe a certain type of foundation for the whole line, to be used both in rock bottom and in the marshes. It is necessary to consider each foundation in the light of the character of the ground, and not only the character of the ground when inspected, but the condition it is likely to be in at the worst time of year.

The experience with lightning appear to be the same as with the ordinary high tension lines. Some plants had trouble, and others did not. There are some cases where the hooks in cement types of insulators have pulled out. Sleet has been reported weighing 1.9 lb. per running foot on No. 0 wire. This means over two inches in diameter, outside of the wire, if symmetrically spaced. One report was brought in of six inches of sleet, but the manager of the plant suggested that "possibly that was an exaggeration."

M. H. Collbohm: I note that some of the operating companies are using the ungrounded delta system. I would like to know what the considerations were which guided these companies in deciding for such a system. It would seem to me that the disturbances set up by an arcing ground in a system with exceptionally long lines operating under very high voltage, would be very marked. It has been stated that the aluminum arrester would be able to take care of such disturbances, but I have had experience in an ungrounded delta system, where such a type of arrester, properly installed and pronounced in good order by the manufacturer, had been blown up three or four times, without lightning being the cause, simply by surging, and it seems to me that perhaps the grounded Y system might be preferable.

Digitized by Google

Paul M. Lincoln: My experience with the grounded neutral on high tension lines has been of a secondary nature for the last five or six years—it has come second-hand, so that anything I may say on the matter of grounded neutral is necessarily information that came from some one else to me. However, making a general analysis of such information as I have been able to gather, I have formed the general opinion that the grounding of a neutral of high tension transmission lines, preferably through a resistance, is a desirable practice. Some transmission lines, particularly those in the western states, have made a practice to dead ground their neutrals, and in some cases have gone so far as to use the ground as a conductor. Some single-phase customers of these transmission lines have been served by a single conductor, using the ground as a return. That is carrying the grounded neutral idea to its further point. However, in general, from such observation as I have been able to carry out on the transmission lines, I find that the grounding of the neutrals, although it tends to emphasize some difficulties, tends to reduce others, and in my opinion the reduction of the difficulties is greater than the increase, due to that method of operation.

L. C. Nicholson: Concerning the question of grounding the neutral of a high voltage transmission system, I agree with Mr. Lincoln that grounding through a limiting resistance gives best results. A neutral completely grounded is open to several grave objections. A ground on one wire constitutes a short-circuit through the earth as a return. This usually interrupts the delivery of power, causes destructive inductance in parallel telephone or telegraph circuits.

With the neutral insulated arcing grounds composed of the charging current of the system set up dangerous surges which often cause failure at some other point and thus develop into a phase-to-phase short circuit.

The advantage of inserting say 1,000 ohms in the neutral of a 60,000-volt line are several. First, the earth current is limited to a value which does not disturb the voltage of the system and therefore does not disturb the load. Furthermore, such an arc is not persistent and will usually cease after a few seconds without the necessity of cutting out the line, which is not true of an arc carrying large current as in the case of a neutral grounded without resistance. The chief advantage of resistance in the neutral is that it largely overcomes the fundamental objection to an ungrounded neutral, that is, surges. The fact that the arc carries a small power current, and not condenser current only tends to make the arc a better and more continuous conductor, which prevents the rapid make and break effect of a true capacity arc, and in this way an arcing ground loses its power to produce destructive voltage surges.

An operating advantage of a resistance is that a line or section of line equipped with oil switches may be cut out automatically in case of a ground on one conductor. This is not true of an ungrounded neutral.

Digitized by Google

N. J. Neall: The question as to whether a line should be operated without grounded neutral or with grounded neutral is, of course, an old one that we have all battled with, and I suppose, judging from what has been said this morning, that neither method is objectionable, provided it does not interfere with continuity of service.

There is one point, however, which the inquiries sent out by the Committee did not cover, and I think it of great interest, and that is the question—How do these large operating companies take care of customers on branch lines? Do they permit the branch customers to be tied into the main line directly, or do they operate them through oil switches or fuse connections? There seems to be no information on that score, and it is, I think, one of some importance.

As far as lightning protection is concerned, I observe that Mr. Jollyman speaks of the electrolytic lightning arrester as having a definite limit of operation and recommends that the gaps shall presumably be set above the critical voltage of the transmission line. This is rather an extraordinary point of view, and does not coincide with the opinions expressed in the report made to the Committee of the National Electric Light Association, on Lightning Protection, of which I happen to be a member this year, and in which we had some very full replies. The general impression in reading the returns would be that the electrolytic lightning arrester had established itself positively in operation without very much trouble. Its operation, however, has created difficulties which are being recognized and corrected, and I can simply say to you as a matter of record, because it is no secret, that you must be very careful not to take your electrolytic lightning arrester for granted. The electrolytic lightning arrester and other forms of lightning protective arresters are not widely different from the class which we call fuses, and while they represent a certain outlay, and loss is undesirable, yet I see no reason to object, if the loss of the electrolytic or any other type of lightning arrester is simply, presumably, to save your main generating apparatus. It represents, however, a standard which the users of apparatus are already creating, namely, that as generating apparatus, transformers and other types, are becoming stronger against static disturbances, and they are having less failures, they are demanding that the protective apparatus which they were formerly willing to see fail, provided it saved the rest of the station, shall likewise increase in strength, all of which is piling up the insulation at all points, and they are thus expecting to have no interruptions whatsoever. I think that is a very difficult ideal to attain at the present time. The general improvement of arresters, plus the value of overhead line protection, has materially changed conditions, as they were reported to the Committee, and in this connection, I have a communication from Mr. Vaughan, which follows:

J. F. Vaughan (communicated): The chairman of your High Tension Transmission Committee has asked for information on

Digitized by Google

the results of the operation of the lightning protection devices adopted for the Taylors Falls transmission line of The Minneapolis General Electric Company, following the experiments which were published by the writer in the TRANSACTIONS of the A. I. E. E. for May, 1908.

The original line, about 40 miles long, was built in 1905, operating at from 50,000 to 55,000 volts. It consists of wooden pole construction, carrying a three-phase line of No. 4/0 B. & S. gauge copper cable, arranged on a 72-in. upright equilateral triangle. The original protection consisted in "low equivalent" multigap arresters at each end of the line, a double gap selective resistance horn arrester at the power station, a single horn gap water resistance arrester at the substation, a triple gap selective resistance horn arrester at the middle of the line, and an electrolytic arrester without oil insulation at the substation. The line protection originally consisted in four experimental half-mile sections of different forms of overhead ground wire, with occasional lightning rods on the transmission poles and also a few rods on separate poles alongside the line. The most pronounced effect was produced by the type of overhead ground wire consisting of two No. 6 ground wires mounted 6 ft. apart 18 in. above the top transmission wire, which appeared to shield the line effectively, preventing spillover and breakdown of insulators. These troubles were frequent and serious on the unprotected portions of the line. The station protection was satisfactory.

The success with the overhead ground wire led the company to extend it year by year until the whole line was protected. Line failures and disturbances decreased in proportion as the ground wire was extended.

This year a duplicate line was built alongside the first line, using semi-flexible "A" frame steel towers, with the wires arranged in an inverted 72-in. equilateral triangle with a $\frac{3}{8}$-in. steel cable ground wire at the apex of the tower. Electrolytic arresters were installed in connection with the new line at both stations and the power station horn gap arrester was replaced by an electrolytic arrester as well. The horn arrester at the middle of the line was found unnecessary and removed.

This season, up to the present writing, there have been 22 thunder storms without causing any interruption to service on either the pole line or the tower line. In this and other points the operation of the system has confirmed the conclusions drawn from the original experiments as reported in the above mentioned Institute paper.

Hugh Pastoriza: Mr. Hebgen mentions the swinging of suspension insulators in the direction of the line due to temperature effects on adjacent spans of unequal length. This is an interesting point and one which we have investigated in some detail in connection with line design for the Telluride System.

As would be expected, the amount of deflection of insulators

Digitized by Google

is greater the longer the spans concerned. With a given maximum span the greatest deflection occurs when the adjacent span is approximately half the size. The worst condition appears to be five or six equal long spans adjacent to a series of five or six spans half as long.

This swinging may be minimized by a proper proportioning of sags in the various spans. Ordinary practice is to stress all spans to the same amount (usually to the elastic limit) under maximum load and at fairly low temperature. This results in a very large unbalancing of tension between a long and a short span at low temperature when unloaded. If the tensions are equalized at average temperature and loading instead, the unbalancing of tension under extreme conditions is much diminished and the swinging of insulators considerably reduced. This method of stringing results in greater sags on the shorter spans than are given by the usual method, but as difficulties with ground clearance usually occur on the longest rather than the shorter spans, this is not objectionable.

In some cases computed where tensions were not thus equalized, insulators were found to deflect as much as 30 degrees. This emphasizes Mr. Hebgen's point regarding the desirable construction for wire clamps.

Digitized by Google

DISCUSSION ON "A THEORY OF COMMUTATION AND ITS APPLICATION TO INTERPOLE MACHINES," NEW YORK, OCTOBER 13, 1911. (SEE PROCEEDINGS FOR OCTOBER, 1911.)

(Subject to final revision for the Transactions.)

H. F. T. Erben: When I learned that Mr. Lamme had written a paper on the subject of commutation I was in hopes that at last we would see an exposition on the subject from which would be absent the familiar "K" which is found in all formulae so far developed by various writers. I find however, that the "K" is still freely used and that Mr. Lamme has been unable to develop formula which brings the subject of commutation down to what we might call an exact science. I do not wish to disparage Mr. Lamme's ability to produce such formulae I firmly believe that there are so many variables, both of the mechanical and electrical nature, entering into the subject of commutation that the derivation of a formula without constants is simply an impossibility. I think we will have to remain content with formulae of a skeleton nature, upon which the designer will build the finished product. I think that the merit of Mr. Lamme's paper lies in the method in which the subject matter is presented, rather than any new or fundamental ideas.

Of the three fluxes which Mr. Lamme considers, the first two have always been thoroughly considered in making our calculations. I have not studied the paper sufficiently to get a clear idea of what Mr. Lamme terms the "slot flux". I think, however, that what he terms the "slot flux" is identical with what other authors have termed "flux set up by the coils undergoing commutation". The fact that the formula which Mr. Lamme uses for determining the e.m.f., due to slot flux, is very similar to that used by other designers, confirms this opinion.

In the latter part of Mr. Lamme's paper he states that up to the present, little has been done in the way of determining the maximum overload capacity of machines at the time of short circuits. A little over a year ago we carried out a long series of tests on machines of the commutating pole type and compensated type with a view to determining the maximum momentary overload which could be carried without flashing over. The result of these tests show that an overload of 10 to 12 times normal, will cause a complete flash over and that momentary overloads of seven or eight normal, will cause very severe sparking and flashing around the brush holders but the machine is not liable to completely flash over. The compensating winding permits a machine to carry a somewhat heavier momentary overload but the gain is not very great. Oscillograph records taken at the time of short circuits show that in the case of a compensated machine there is less field distortion than if commutating poles alone are used and in consequence a machine fitted with compensated winding will carry a somewhat greater maximum load before the flashing over point is reached.

Digitized by Google

Photographs taken at the moment of short circuits show that a considerable amount of gas or vapor is generated, due to the brushes and commutator copper being momentarily heated to incandescence. This gas being of high conductivity permits the establishment of an arc between the brush and the commutator segments.

The formation of gas as effecting flashing is clearly shown by the fact that if half the brushes are removed from the commutator the machine will flash over at a lower current value than if the full set of brushes are present.

We are all very much indebted to Mr. Lamme for this paper as he has presented the subject of commutation in rather a new light and has thereby stimulated general interest in a subject which has of late years been neglected by those presenting papers before general technical societies. I hope that this paper will serve the purpose of inducing other members to present their views on this most difficult and complex subject.

Geo. L. Hoxie: The way in which Mr. Lamme has put together his qualitative description of what goes on in a machine seems to me to be open to some criticism. The point I wish to make is that you cannot consider magnetic fluxes separately, each as being a flux due to a particular m.m.f. taken alone, and then add up these component fluxes and get the resultant flux. That is to say, you cannot do this where you have magnetic material in your magnetic circuit, and especially where some parts of the magnetic circuit are saturated, as will usually be the case.

In a direct current generator we have at no load a more or less uniform flux under the pole faces, a very dense flux through the armature teeth, etc., all due to the field currents. With load, armature currents superimpose their m.m.f. upon the m.m.f. of the field and the resultant m.m.f. produces a resultant flux which as a rule is not at all the geometric sum of the fluxes that would be due to each m.m.f. taken separately. This is the very result that electrical machinery designers found it necessary to strive for from the beginning, and they usually expressed the thing by saying that the distortion of field flux due to armature reaction was largely minimized by a strong field, liberal air gap, and by saturation, in pole tips, pole faces, and armature teeth. In the very early machine it was not uncommon to have the magnetism in one set of pole tips reversed by armature reaction. Such a state of affairs meant a tremendous field distortion, and brought with it very bad commutation.

I would take issue with Mr. Lamme on the proposition that field distortion has nothing to do with the problem of commutation. As I understand the problem of commutation it is ideally desirable that during the time a coil is short-circuited by a brush, the coil should have generated within itself an e.m.f. opposed to the current that the particular coil carried a moment earlier. Also that the e.m.f. of the short-circuited coil should be exactly enough to stop the old current in the coil, start a current

Digitized by Google

in the opposite direction, and bring this new current up to the exact number of amperes that are flowing in the coils next beyond. If all of this occurs exactly during the time that the coil is short-circuited, ideal commutation will result. If the brushes be given no lead, zero e.m.f. is generated at no load in the short-circuited coil. The correct lead used to be found by experiment. Then as load increased, the field distorted, and a new commutating position was found, also by experiment. With the introduction of carbon brushes, and saturated magnetic circuits, machines were produced that did not require a constant shifting of brushes to follow up the distorted field. This was largely because only a little distortion occurred.

Now we come to interpole machines, which are rather a new thing. In these machines the effort is made to set up a m.m.f. proportional to the armature m.m.f., and either equal to, or a little greater than, the armature m.m.f. This means practically an effort to balance, or neutralize, armature reaction, at least so far as concerns the field through the coils being commutated. It is found that neutralizing armature reaction in this manner produces very excellent commutating results, and the interpole machines are getting quite popular.

I do not intend to discuss interpole machines but I do want to say that about 21 or 22 years ago Professor H. J. Ryan designed and patented a pole-face winding, so called, which was simply a distributed interpole winding, or was a series winding distributed in the pole faces just outside the armature, having ampere turns equal and opposite to the armature ampere turns. Those machines also commutated excellently. I have always believed, and I still believe, that had the Ryan patents been owned by one of the big companies instead of by a rather small concern we should have seen direct current development proceed upon quite different lines. Probably these patents have expired by this time, and possibly they would cover the interpole machine if still in force.

Perhaps we shall yet see the pole face winding, or some modification of it, such as I take the interpole to be, come into wide use. It will certainly pay students of direct current machine design, and of commutating problems, to look carefully into this early work of Professor Ryan's.

H. M. Hobart: In listening to this very interesting abstract by Mr. Lamme it occurred to me what a capital thing it would be if the International Electro-Technical Commission could standardize some commutation criterion. Each of us has a theory of commutation and each believes that his own theory serves the case admirably; but we have great difficulty in interchanging views. We all speak the same mother tongue, and yet nevertheless language differences exist which make it quite difficult to follow another's exposition of the subject. Now, I have felt this in reading Mr. Lamme's paper. Already at the first reading I could see that a great deal of valuable information was con-

Digitized by Google

tained in the paper, and yet it took a lot of study on my part before I began to grasp the full significance of Mr. Lamme's point of view, and as my study of the paper progressed, I found that the differences between the way we are often in the habit of looking at it and the way in which I saw Mr. Lamme regarded it, gradually decreased until it seems to me it is largerly a matter of expression. I have usually obtained pretty good results from considering the voltages in the short circuited coils as arising largely from various components and it has only seemed worth while to take the two principal of these components into account. Mr. Lamme speaks of a component voltage associated with slot fluxes and a component voltage associated with end winding fluxes. In addition to these he lays a great deal of stress on a third component, that associated with the interpolar flux.

It is difficult to deal with this third component in any except one of the three cases which naturally present themselves. There is, first, the interpole machine; then secondly there is the non-interpole machine in which you advance the brushes a little to overcome sparking, and thirdly there is the non-interpole machine operated with the brushes in the geometrical neutral position. As to the first of these types, the armature m.m.f. which would (were no interpoles present) set up the interpolar flux, is overcompensated by the m.m.f. of the winding on the interpole. As to the second type, I agree with the previous speaker that Mr. Lamme's method of treatment is faulty, since he combines fluxes instead of adhering to the combination and resolution of m.m.fs. It seems to me hopeless to tackle the problem in this incorrect manner. But in the third type, the difficulty largely vanishes. We there have an arrangement in which the armature m.m.f. is alone of any account in the position midway between pole tips because the main field fluxes are symmetrically disposed with reference to the resultant armature m.m.f. The difficulties met with in determining the interpolar flux in this third type relate mainly to the estimation of the reluctance of the path followed by that flux from the center lines on the armature periphery until the flux finds a landing place in the main magnetic circuit. For my part, I never had the temerity to attempt to calculate that flux. I think Mr. Lamme is entitled to credit for his courage in undertaking the job. In the abstract which he gave us Mr. Lamme states that we need a different formula for calculating the interpolar flux for each different type of magnetic circuit.

I rather anticipate that there will be considerable difficulty in calculating that flux. Nevertheless, it is well worth trying. I wish that Mr. Lamme had given quantitative figures of representative machines, setting forth the amount of each of these three components of the sparking voltage. I am very interested in Mr. Lamme's statement that in a certain design this third component was greater than the sum of the other two

Digitized by Google

components. As far as I can see, that could only have been the case in rather a bad machine. In my designs, I have always sought to minimize the interpolar flux. A chief means to this end is to have as wide a neutral zone as possible. This usually involves having a fairly small pole arc and a considerable distance between pole tips. The interpolar flux may also be maintained low by designing with a weak armature and a strong field, but of course such a design is relatively expensive.

After careful reflection I feel disposed to give very serious consideration to Mr. Lamme's proposal to take into account this third component in addition to the two components usually considered, indeed, we have always done it in one way or another, for of course we all recognize that the reactance voltage formulae we use are empirical, and if we decide on employing three components instead of two, then we shall distribute the resultant voltage amongst the three components in as suitable a proportion as our ability to analyze the data at our disposal will permit us.

Mr. Lamme gives no attention whatever to one point of considerable importance in the study of commutation. We can correctly deal with the reactance voltage nowadays. When the reactance voltage must be high, we neutralize it by the introduction of interpoles. Amongst other advantages this permits of building motors whose speed may be varied over a wide range by controlling the current in the shunt field. But while the reactance voltage now presents no difficulty in such machines the commutation may still be very bad through having too great an average voltage between adjacent commutator segments. At the motor's highest speed the maximum voltage between adjacent segments will often be several times greater than the average voltage between segments. This is because the armature reaction quite overmasters the normal field. It may lead to 40 or 60 volts between the segments when the average voltage between segments is only—say—10 or 15. Now that brings us to the border line of commutation trouble of a kind which has nothing to do with the reactance voltage.

The introduction of interpoles has tempted designers to increase the reactance voltage. Indeed, there has been a temptation to take great liberties in this direction, such as decreasing the number of segments with a view to cheapening the machine. This has resulted in increasing the average voltage between segments and has increased still more the maximum. I have pointed out this omission to deal with the average and maximum voltages between adjacent segments as I consider that in a modern theory of commutation their consideration is of no less importance and may even be of greater importance than the consideration of the reactance voltage.

Returning for a moment to a consideration of Mr. Lamme's third component of the reactance voltage, *i.e.*, the component associated with the interpolar flux, it will obviously be a function of the armature strength in ampere turns per pole. For ma-

Digitized by Google

chines with the same armature strength and the same number of poles, this third component may for armatures with one turn per commutator segment, be expressed as a function of the product of the gross core length (λg) and the speed in revolutions per minute (R). It is interesting to compare this result for Mr. Lamme's additional component with a result in my article published on page 6 of *The Electrician* for April 20, 1906, and which is further developed on page 336 of Hobart and Ellis' "High Speed Dynamo Electric Machinery", from which I abstract the following portions of an extensive table for facilitating estimations of the reactance voltage:

Table of factors to be employed in obtaining the reactance voltage in terms of the gross length of the armature core and the speed in revolutions per minute.

Armature strength in ampere-turns per pole	Values of K in the formula: Reactance voltage $= K \times \lambda g \times R$ for the numbers of poles set forth at the heads of the vertical columns		
	4	8	16
8000	0.000256	0.000512	0.001024
4000	0.000128	0.000256	0.000512
2000	0.000064	0.000128	0.000256

From the above table it is seen that I have resolved the first two components (slot and end connection components) down to a simple form to which the "interpolar" component can also be reduced. Nevertheless, it would appear to be desirable to keep in mind that the result is a combination of *three* important components instead of comprising only *two* components.

We must always remember that electromagnetic considerations are by no means the only ones affecting commutation. Various mechanical conditions may be and often are of predominating importance. These are often not susceptible of *quantitative* predetermination. Thus who can calculate the extent of the improvement in commutation which will attend grooving out the mica between segments, or the use of a grade of brushes of different composition and construction, or the substitution of a different type of brush holder, or a low peripheral speed of the commutator? We know that we can often very greatly improve commutation by attention to these points and that we may then safely employ higher reactance voltage and higher average and maximum voltage between commutator segments, but we can rarely make quantitative statements of the extent to which we shall obtain advantages by these means.

Malcom MacLaren: The method of treating the theory of commutation proposed by Mr. Lamme throws a great deal of light upon this very complex problem, and should allow a clear analysis to be made in many special cases where the problem had previously appeared hopelessly involved.

The formulae which he derives appear at first sight rather formidable, but, as he explains, these can be materially simplified when applied to a single class of machines. For example for

Digitized by Google

four-pole machines with the poles covering $\frac{2}{3}$ of the armature circumference the expression for E_c becomes:

$$E_c = \frac{14.7\, I_c\, W_t\, T_c\, R_s\, L}{10^8}$$

A somewhat closer approximation can be made for four-pole machines by substituting 82 for 90 in the value of b and substituting $\frac{\pi D}{12}$ for $\frac{P}{2}$ in the expression for a. These changes would simply alter the constant in the above expression for E_c and make this 16.8 instead of 14.7. For any greater number of poles the approximations which have been made in the general solution are very close. A further modification might be introduced however, to take care of the effect of armature slots, for the expression given in the general formula shows the e.m.f. which would be produced in the coil under commutation due to the interpolar flux, if this coil were on the surface of the armature. This correction would of course be slight except in the case of comparatively small diameters and deep slots.

It is interesting to note that this method of treatment shows clearly that a full pitch winding commutates under better conditions as regards the interpolar flux than a chorded winding. This effect, however, is not large even with considerable chording when account is taken of the neutralization of the armature conductors in the chorded zone. For example, with the pole covering $\frac{2}{3}$ the polar pitch and with chording $\frac{1}{2}$ of the interpolar space the effective ampere turns will be 5/6 of the ampere turns with full pitch winding. The length of path from the coil under commutation to the nearest pole will be $\frac{1}{2}$ the length of path for the pitch winding, and the length of path to the more distant pole will be $1\frac{1}{2}$ times this distance, so that the mean effective path for the chord winding will be $\frac{3}{4}$ of the path for the pitch and the strength of field will be $5/6 \times 4/3$ or 10 per cent higher than the field with pitch winding.

The effect of chording upon the slot flux as given in the paper on the basis of the brush spanning one commutator bar is apparently greater than experience with actual machines would suggest. Mr. Lamme's analysis clearly shows that a number of factors enter into the determination of the effect of chording upon commutation some of which tend to neutralize each other, but it would seem as though sparking at the commutator would be more a function of the maximum rate of cutting of the slot flux than the average, which Mr. Lamme has used.

Applying the formula, given by Mr. Lamme, to a number of non-interpole machines for which the commutating characteristics were known, it was interesting to note the relative importance of the various elements contributing to the e.m.f.

Digitized by Google

produced in the short circuited coil. All of the machines investigated had long poles similar to Fig. 3, so that the expression for the interpolar flux in the formula could be used without change. As comparative figures only were desired, the brushes were considered as spanning one commutator bar and were set on the geometric neutral. It was found that for a whole line of slow speed generators the e.m.f. due to the end winding flux remained surprisingly constant at about $\frac{1}{2}$ volt; but for certain high speed machines this value was nearly doubled. The e.m.f. due to the interpolar flux was relatively unimportant in many cases, but for several large generators this became the predominating factor; in the case of a 1500-kw. high speed generator the e.m.f. due to the interpolar flux was 2.8 volts, to the end winding flux 0.9 volt and the slot flux 1.3 volts.

C. A. Adams: Mr. Lamme deserves great credit for the careful and conscientious manner in which he has attacked this ever-new problem of commutation. He has considered several points ordinarily neglected, and has presented the whole subject in such a way as to assist greatly in visualizing a very complicated set of phenomena. The subject is one which in most of its phases does not admit of a very satisfactory oral discussion, since it requires too close an analysis. I should like however to say a few words about the characteristic feature of the present paper, the feature which chiefly distinguishes it from most others on the same subject; it is the assumption that the total e.m.f. induced in a short-circuited coil is induced by the mechanical movement of the coil in question through certain stationary fluxes.

In the more familiar form of analysis a part of this e.m.f. is calculated as if induced by the change in magnitude of the flux linked with and moving with the coil in question, said flux being due and proportional to the current in the coil. When more than one coil are undergoing commutation at the same time, this method demands the consideration of the e.m.f. induced in each coil by the change of current in each of the others, *i.e.*, the consideration of the mutually-induced as well as the self-induced e.m.f. This necessity seriously complicates the problem in the general case, and it was doubtless a desire to avoid this complication that led Mr. Lamme to his present method. The question I wish to raise as to the legitimacy of this method, may be most readily answered by a consideration of the location and magnitude of the various m.m.fs. which go to produce the resultant flux in the commutation zone. *If these m.m.fs. are stationary as a whole, and if the local magnetic circuit is stationary, then will the resulting magnetic flux be stationary.*

Divide the total m.m.f. into three parts: first, the field m.m.f. which is obviously stationary; second, the main part of the armature m.m.f. (exclusive of the current in the commutating zone), also stationary as a whole; and finally the m.m.f. due to the current in the commutation zone, *i.e.*, the current in the coils

Digitized by Google

undergoing short-circuit by the brushes. In order, for the present, to eliminate the question of variable local reluctance, assume a smooth core armature. Assume also a full pitch winding. Then the only possible source of a non-stationary flux is a non-stationary m.m.f. due to the current in the commutation zone.

Consider the current distribution around the periphery of the armature in the vicinity of the commutation zone. In Fig. 1, $B\ C = +I$ represents the current in each coil as it approaches the brush, and $A\ D = -I$ represents the current in each coil as it leaves the brush; the ordinates of the line $C\ D$ representing the time variation of current in each coil during the commutation period, on the assumption of perfect commutation. If there are many segments under the brush and many coils undergoing commutation at the same time, the line $\overline{C'\ C\ D\ D'}$ will represent the approximate peripheral distribution of current in the vicinity

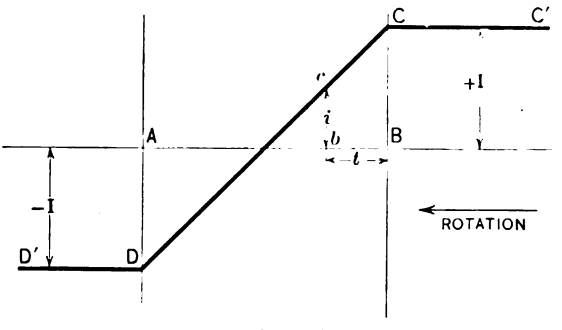


FIG. 1

of the commutation zone at any instant; *i.e.*, each ordinate of this line represents the current in the coil located at that part of the periphery at the instant considered. With any possible number of segments under the brush, each coil will occupy an appreciable part of the zone-width and the peripheral current density will obviously be constant over the coil width. If it were possible to have 16 segments under the brush, the instantaneous current distribution for the case of perfect commutation would be shown by the pair of stairs in Fig. 2, where i_1, i_2, i_3, etc., are the currents in the several coils located at b_1, b_2, b_3, etc. For the case of delayed commutation, shown by the time current curve $\overline{C\ O'\ D}$, the instantaneous space distribution of current would be shown by 16 steps of equal width but of varying height, superimposed on the curve $\overline{C\ O'\ D}$. A little consideration will show that there are slight pulsations in either of these distributions as each coil moves over the width of one step, *e.g.*, from b_1 to b_2, and that these

Digitized by Google

pulsations are less, the larger the number of segments under the brush. In other words, for a large number of segments under the brush, the current and m.m.f. distribution are practically constant. Thus in this case of many segments, the e.m.f. computed on the assumption of a stationary flux (the method being accurately applied) will be exactly the same as that computed on the assumption that there is a self-inductive flux carried along by the current. In the case of a few segments however, the difference is not negligible; *e.g.*, consider the case where the segment width and the brush width are equal. The same assumptions as before are made as to smooth-core armature, full pitch winding, and perfect or straight-line commutation. Then when the coil under the brush has progressed $\frac{1}{8}$ of the way across the commutation zone, the current in the coil, and the peripheral current density over that portion of the armature occupied by

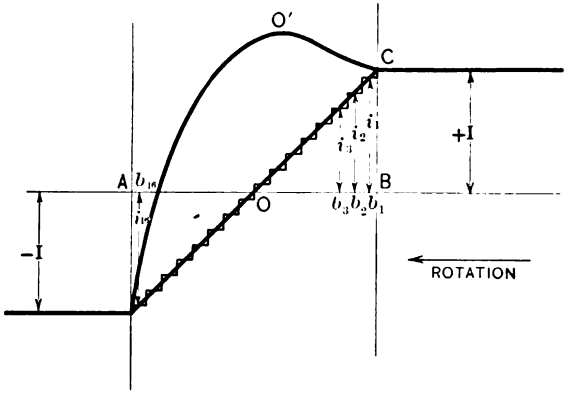


FIG. 2

the coil in question, will have dropped to $\frac{3}{4}$ of their full pre-commutation value. The distribution of current density in the vicinity of the commutation zone will then be shown by the lines marked 1 in Fig. 3. When the coil has progressed 2/8 of the way across the zone, the distribution of current density will be shown by the lines marked 2 and so on. If the commutation is not according to the straight line $C\bar{D}$, but according to the curve $C\,O'\,D$, then will the height of each step be determined by the corresponding ordinate of $C\,O'\,D$ rather than of $C\,D$? In any case it is obvious that with only one coil under the brush, and to a lesser degree with two or three, there is a very considerable pulsation of the m.m.f. distribution in the vicinity of the commutation zone. It is thus no longer legitimate from the theoretical point of view to assume a stationary flux distribution, but more accurate to deal with that part of the armature m.m.f.

Digitized by Google

comprised within the commutation zone as producing a local flux which moves with the armature and varies as the moving current varies. This point of view is still more obviously consistent with facts when it is remembered that in practically all commercial machines the armature core is toothed and that therefore the local magnetic circuit moves with the current. *I.e.*, the reluctance of the local self-inductive magnetic path linked with a group of conductors in a given slot is constant when considered as moving with the conductors, but the reluctance of a local path at any point (stationary with respect to the field poles) of the commutation zone is not constant, but varies as the teeth and slots pass by.

Most of the common simple formulae for commutation reactance e.m.f., give only the approximate *average* value, assuming perfect commutation, and do not take account of the variation

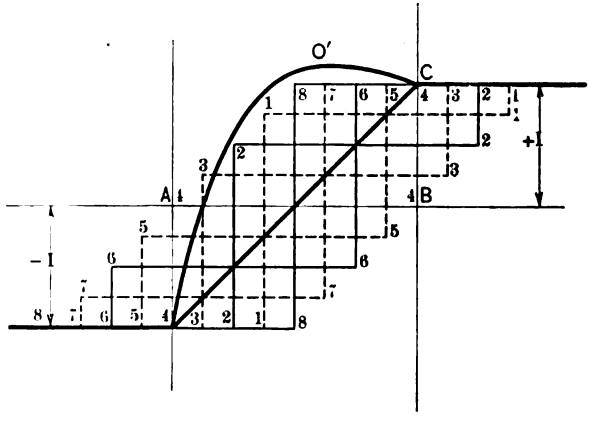


FIG. 3

of the reactance e.m.f. during the commutation cycle. The averaging in this method is equivalent to the assumption of stationary flux in Mr. Lamme's method; *i.e.*, neither takes account of the local pulsations of flux and of the corresponding induced e.m.fs. It is on this account that the principal terms in Mr. Lamme's equations are so familiar. The real essential difference between the common formulae and those of the present paper is that the latter include a number of factors ordinarily neglected.

Mr. Lamme states as evidence of the accuracy and legitimacy of his method, that the results check with the experimental results of tests which give the potential curve under the brush; but it should be remembered that an ordinate of one of these curves is obtained by connecting a direct current voltmeter across the contact surface at the point in question, and is therefore the *average* value of the potential drop, not showing the pulsations.

Digitized by Google

Thus neither Mr. Lamme's method nor the reactance voltage method as ordinarily applied, takes account of the pulsations above described. To do this requires a much more thorough analysis, such as that which Professor Arnold gives in his classical work, " Die Gleichstrommaschine ".

But there is still another source of flux pulsations and induced e.m.fs. besides that due to the pulsations of m.m.f. in the commutation zone and to the pulsations of local reluctance in the same region; it is the pulsations of the reluctance of the main magnetic circuit linking with the coil undergoing commutation, due to the varying number of teeth under the main field poles. *E.g.*, suppose that the equivalent pole arc is $10\frac{1}{2}$ times the tooth pitch; then in one position there will be eleven teeth under one pole, and in another position only 10, with an approximate change of reluctance of something less than 10 per cent. If the same change takes place under adjacent poles at the same time this will mean pulsations of the main flux, which while much less than 10 per cent owing to the damping effect of the field coils, is nevertheless of sufficient magnitude to induce a considerable e.m.f. in the short-circuited coil. Increasing the number of slots, increasing the length of the gap, chamfering the pole faces, a proper choice of the ratio of the equivalent pole arc to the tooth pitch, or any arrangement which brings the maximum reluctance under one pole at the same time with the minimum reluctance under the adjacent poles, will obviously reduce these pulsations, which though not large on well designed machines, frequently account for otherwise unexplainable eccentricities of commutation.

I was very glad to hear Mr. Lamme agree that with the brushes in the geometrical neutral, the degree of distortion *per se*, has nothing to do with commutation. Since the coil is in the field-neutral, the only e.m.f. is due to the armature flux, which is practically independent of the air gap. With a short air gap there is much greater distortion but no greater flux in the field-neutral zone for a given armature current, and no greater induced e.m.fs. in the short-circuited coils, provided the shortening of the air gap has not increased the pulsations of reluctance of the main magnetic circuit. I have proven this on an actual machine, by reducing the air gap from its normal value of 0.15 in., (1.27 mm.) to 0.02 in. (0.508 mm.), without reducing the current at which sparking commenced. In fact with one armature, of such tooth proportions that the main reluctance pulsations were less with short than with long gap, the commutation actually improved as the gap was reduced. With another armature where the reluctance pulsations were larger with the shorter gap the reverse was true.

It has been claimed or at least intimated in the discussion to-night that because of the numerous non-computable mechanical factors which may seriously affect commutation, it does not pay to go into refinement of calculations in connection

Digitized by Google

with the computable portions of the subject. I cannot agree with this position for two reasons; first, the improvement in the mechanical design and construction of commutators, brushes and brushholders, have vastly reduced the relative magnitudes of the disturbances introduced by these various elements; second, every well developed refinement of predetermination, however slight, is a step in the right direction and well worth while. The time involved in its application is ridiculously small when compared with the importance of the result. Because we can't have the whole loaf is not a good excuse for refusing half or three quarters of it.

I therefore wish to congratulate Mr. Lamme, and to express gratification that a practical designing engineer of his high standing has shown his belief in the importance of careful and refined calculations.

C. F. Scott: I want to comment for a moment on the method which is used by a prominent designer and engineer in doing his electrical work. This paper, aside from the specific results which it gives, is, I think, typical of the man. He uses physical methods of analysis rather than mathematical formulas. He may use mathematical methods; he is a mathematician, but it is rather a method than a kind of machinery that he employs. For example, in simple things he does not happen to use a slide rule, but with a little lead pencil and a good deal of mental arithmetic he can set down the answer quicker than most men can use the slide rule. So in his handling of the larger problem, he has a sort of short cut method which enables him to get his results by a kind of physical analysis which is exhibited to us in the paper without very much mathematical machinery being apparent in it.

In the present paper he has treated the matter of commutation not as a limited and particular problem involving only an isolated coil, but he has somehow made it a part of the general problem of the cutting of a stationary magnetic field by moving conductors; so that commutation comes into the general class of phenomena which are involved in the generation of electromotive force in the armature.

Nine years ago at the opening meeting of the Institute for that year Mr. Lamme presented a paper on single-phase motors. There was a great deal of interest in that paper, and it was thought that he must have some mysterious method which would account for the commutation of alternating current. He simply insisted that there was nothing magical about it, that he simply had a machine of exceptionally excellent commutation. Now, his paper tonight reveals somewhat of the method by which he has presumably handled not merely his direct current commutator problem, but also the problem of the alternating current which led to the motor.

The paper, therefore, can be commended as an excellent example of a method of handling engineering and design problems.

Digitized by Google

James Burke: I had not intended to make any comments upon this excellent paper of our friend, Mr. Lamme, especially as regards the interpole feature; but Mr. Lamme has explained in this paper the reason why we have been doing many of the things that we have been doing for a great many years, which arouses much interest. I think all manufacturers of commutating machines have for 20 years stated that their machines operated sparklessly, that there was no sparking under any conditions. This paper tells us why they have operated sparklessly.

An interesting point brought out in the paper is the matter of the fractional pitch as compared with the full pitch of winding. Mr. Lamme's paper mentions the influence of fractional pitch where commutating poles are used. Machines have been built by some companies for many years with various degrees of fractional pitch, and many were built as low as 70 per cent of fractional pitch. However, introduction of the interpole necessitated increasing the pitch so as to bring the commutated coil under the interpole. I think that pretty generally it has been found that in interpole machines the pitch of the coil must nearly approach a full pitch in order to get the best results of the introduction of the interpole, except in the exceptional cases where the end winding becomes a large factor.

I think we must not assume that because we have this paper that any one without any additional experience can build a non-sparking machine, because there are a great many other items of very great importance that are not brought into consideration here. For example, this paper does not introduce the question of the width of the mica between commutator bars. The customary machine has a width of mica of about 1/32 (0.794 mm.) of an inch. Under certain conditions of design, very marked improvement can be obtained by increasing the width of the mica. I have had experience with machines in which with the ordinary width of mica the machines would have been impossible of successful operation, but by introducing increased widths of mica into the design, in some extreme cases to about $\frac{3}{8}$ of an inch, (9.525 mm.) or about 12 times the usual practice, the machines were entirely successful. The improvement in commutation due to wider mica is a study by itself, but one of the important factors introduced is the increased effect of the resistance of the brush in the path of the short circuit coil, because the path through the brush although variable, has a minimum length equal to the width of the mica, and by increasing the mica, that path is increased so that the effect of the resistance of the brush is very markedly increased. There are difficulties in getting mica that will wear evenly with the copper in the commutator, but this can be overcome by scraping the mica lower than the copper. As an example, I know of one motor that if its criterion of commutation be judged by any of the well known formulae, would be declared impossible, and yet this machine, operating

Digitized by Google

as a reversing motor with its brushes at the geometrical neutral, has been operating for some years carrying intermittent loads in excess of what would be considered normal for this size of machine. The feature of the width of mica is a very important one in the study of commutation.

The question of finding the geometrical neutral is one that is difficult and takes considerable time as mentioned by Mr. Lamme, especially if the coils are fractionally pitched, and more especially if the armature is twisted so that the teeth do not enter evenly under the pole. The proper position as mentioned by Mr. Lamme is very important in interpole machines. A method that we have used for many years might be of interest and is a time saver. It will be better understood by the following diagram, Fig. 1, in which a two-pole machine is used for illustration: *A-A* represent the poles; *B* the armature; *C-C* the brushes; *D* any one of the armature coils, shown in the diagram as being the coil short circuited at that instant by one of the brushes, and in the illustration being at the geometrical neutral, the pitch of the coil being slightly fractional in the illustration. *F-F* represent the field coils excited from an external exciting supply, which field excitation can be thrown on or off by means of switch *H*. Across the brushes is connected a low reading voltmeter *I*. Now if the switch *H* is opened or closed while the armature is stationary, there will be an instantaneous deflection of the indicator of the voltmeter, if the brushes do not happen to be at the geometrical neutral. By moving the brushes, the deflection at opening or closing the switch will decrease if the brushes are moved towards the geometrical neutral, until finally there will be no instantaneous deflection of the voltmeter when the brushes are on the proper neutral position. Instead of making or breaking the field, it is sometimes more convenient to simply use switch *H* for interposing resistance in the field circuit. The foregoing gives the true position both for machines without interpoles and with interpoles for the geometrical neutral. This is the starting point from which the brushes are moved to aid commutation when brush movement is resorted to. Also in the interpole machines in cases where the interpoles are not of the proper strength, some departure from this position will be found necessary to correct for incorrect strength of interpoles.

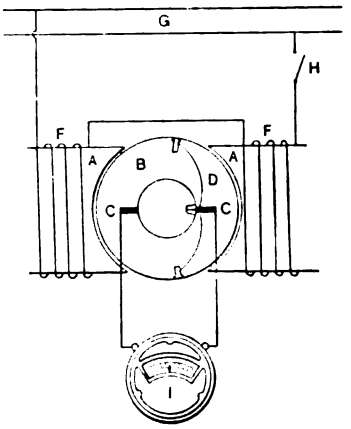


FIG. 1

Digitized by Google

This paper takes up only one kind of interpole construction, perhaps the most inefficient kind of interpole because it is that which takes the largest number of ampere turns for producing commutating zones of the correct condition for commutation. For instance, another extreme in the comparison with this may be illustrated by the following sketches, Figs. 2 and 3. Fig. 2 shows the ordinary type of interpole which is the form referred to throughout Mr. Lamme's paper. If the armature strength is for example, 10,000 ampere turns per pole, it would be necessary to have somewhere between 12,000 and 14,000 ampere turns on the interpole, all of which magnetization is accompanied by copper loss in the production of that field and that loss is very often as large and sometimes larger than the other field losses. In some cases the total field losses are doubled by the introduction of interpoles. Now in contrast with this,

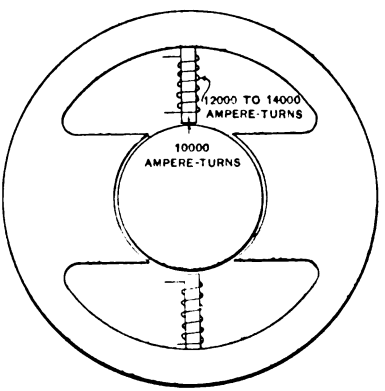


FIG. 2

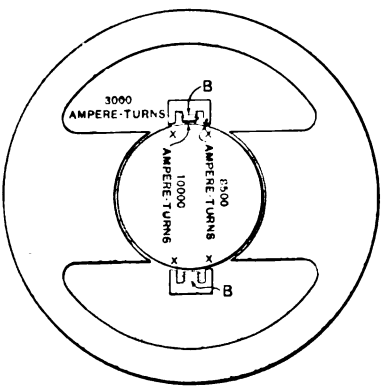


FIG. 3

another way of producing a suitable commutating zone is shown in Fig. 3, in which *B* indicates the interpoles supported from the magnet frame in any suitable way by non-magnetic material. Assuming again an armature magnetization of 10,000 ampere turns at the middle of the interpole, we can find a point indicated approximately at *X* in Fig. 3, at a convenient position mechanically and electrically which will have a strength of approximately 8,500 ampere turns, so that the winding on this type of interpole will require a magnetization of only the difference between the 10,000 point and the 8,500 point, equals 1500 ampere turns, plus that necessary for overcoming the air gap and magnetic circuit of the interpole in producing the desired commutating flux, or in the illustration approximately 3,000 ampere turns. It will be seen that with this type of interpole, with approximately 3,000 ampere turns, if properly designed, the same effect can be accomplished as with say—12,000

Digitized by Google

ampere turns, in the type of interpole shown in Mr. Lamme's paper. This particular type is one that I have given considerable attention to in investigation and in tests, and believe it shows a greater promise than the old fashioned interpole that has been customary.

I note with interest Mr. Lamme's remarks on using a lesser number of interpoles than main poles. When we first started doing this some people thought that we had left something off the machine, particularly in two-pole machines where we used only one interpole, and in some six-pole machines with series connected armatures, where we used only two interpoles, but the success in the operation of the machines with a lesser number of interpoles than main poles when properly proportioned warranted this use, and I think Mr. Lamme confirms the correctness of using lesser interpoles than the total number of poles, provided you can get your other magnetic conditions correct.

One other point of great importance is, I think, not fully treated in the paper, and that is the effect of the number of coils per slot. We find in machines sometimes as many as five per slot and five commutator bars per slot. The difference in the effect between one commutator bar per slot and many bars per slot is a matter of very serious consideration in the designing of interpole machines.

I regret that I did not have an opportunity to study this paper fully so as to be able to discuss it, and I will only conclude by expressing gratitude for the contribution which Mr. Lamme has made to the recorded knowledge on the subject which is available to those who are studying the designing of commutating machines.

R. B. Treat: Mr. Lamme's paper covers in a step by step manner several of the factors affecting commutation. The development can easily be followed, and each final formula has a real physical conception.

The last formula for B_i would seem to require a correction factor of $2/\pi$ due to the distributed magnetizing armature winding. One eminent author omits to apply this factor in his discussion of direct current machines, but does apply it when he discusses synchronous machines. Why he draws the distinction is a question to me.

Fig. 10, of the paper, shows a flux density diagram to the right of the slot picture. This shows a straight line increase of flux from the base of the conductor d to its top. The author appears to assume that the e.m.f., developed in the conductor of depth d by this flux is proportionately to one-half d. Extensive experiments have shown that the e.m.f. curve for the conductor of depth d will take the form of a parabola and the average e.m.f. is proportionately to $\frac{1}{3}\ d$.

The formula for flux from tooth top.....contains the factors $0.54\sqrt{n}$ I have been unable to verify this part of the formula for experiments had indicated that it should be a logarith-

Digitized by Google

mic function of the armature core surface enclosed by the coil divided by the slot width. Again there seems to be no reference to the flux set up in the end connections by the commutating coil, this end flux being entirely independent of that referred to on a previous page which gives calculations for end flux set up by the armature magnetizing turns.

There is a chapter headed " Condensed approximate formula." The designer might well omit this chapter and adhere closely to the previously developed individual formula, for he may then easily note the effect of minor changes upon the design.

In the discussion of the effect of brush width given in the paper, I would ask if the factor B_i is not intended to be B_1 to conform to the value as given under the heading " Effective Armature Ampere Turns?"

The paper presents a theory of commutation which looks complicated and cumbersome, but if the designer will adhere to the elements which have been developed, he will find that the matter is of very easy application and it insures a little more accuracy than may have been obtained heretofore.

C. E. Wilson: During the preparation of the paper by Mr. Lamme I was engaged for a considerable time in checking over a large number of machines with the idea of verifying the formulae by tests. In other words, I have made practical application of the substance of the paper, not only in checking the tests on existing machines, but also in predicting the commutation on new designs. While engaged in this work I have been especially impressed by the importance of " over-compensation " and by the necessity for obtaining an approximately uniform distribution of current under the brushes.

A great deal of light can be thrown on these subjects by what are commonly called " brush curves ". These curves are taken by reading the voltage between a point on the end of the brush near the commutator and a point on the commutator directly beneath. This voltage is a rough indication of the current density under the brush; but it is only an indication and not a measure of the current density, for, as is well known, the resistance between the brush and the commutator is exceedingly variable.

Fig. 1 shows the effect on the brush curves of changing the magnetizing force of the interpoles. These curves were taken at full load on a 1,500-kw., 500-rev. per min. machine, which has a high short circuit e.m.f. Curve *a* was taken with the machine under-compensated and sparking slightly; Curve *b* with it commutating perfectly, and Curve *c* with it over-compensated and sparking about the same as when Curve *a* was taken. These curves are characteristic. The current crowds to the leading tip when the machine is under-compensated and to the trailing tip when it is over-compensated.

In Fig. 2, Curve *a* was taken on a 15-h.p. motor at $\frac{3}{4}$ load. Curve *b* was taken on the same motor at the same load with

Digitized by Google

brushes only half as wide, but with twice as many brushes per arm, so that the average current density was the same for both tests. Curve *a* shows flat compensation, while Curve *b* shows the machine to be under-compensated. This result is consistent with the theory advanced this evening. The difference would be more marked if this machine had a higher short circuit voltage due to the slot flux.

Changing the interpole gap has, of course, an effect on the brush curves similar to that produced by changing the interpole ampere turns. Fig. 3 shows tests at full load on a 125-kw. generator which has a low short circuit voltage. Curve *a* was taken with a $\frac{1}{4}$-in. (6.350 mm.) interpole gap and *b* with a 5/32-in. (3.969 mm.) gap, all other conditions being the same for both tests.

The same kind of brush curves can be taken on non-interpole

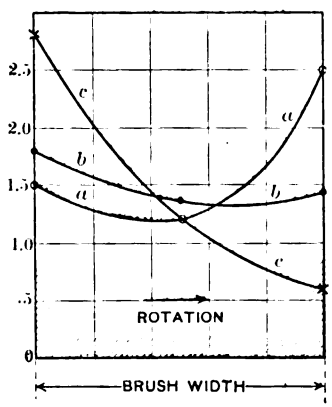


FIG. 1

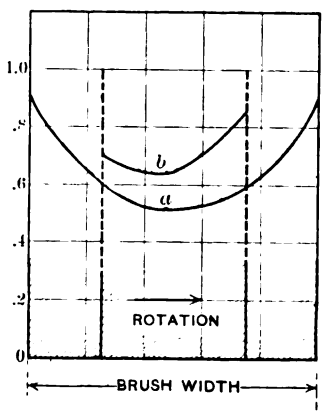


FIG. 2

machines. It is customary to shift the brushes of such machines to assist commutation. The short circuited coils, being in an active field at no load, have large local currents set up in them, which fact shows clearly in the brush curves. Fig. 4 shows the tests on a 100-h.p. non-interpole motor at no load and full load with the brushes given 2.7 bars lag. This machine commutated perfectly at no load and full load and only sparked slightly at $1\frac{1}{2}$ load. The short circuit voltage per coil on this machine is 3.1 volts from test and 3.0 volts by calculation—a very close agreement. The test value of this short circuit voltage was obtained directly from the brush curves taken at no load and full load.

A good way to look at this problem is that, with the brushes on the no load neutral and the brush covering only one bar, the difference in voltage between the two edges of the brush is equal to the short circuit voltage per coil. For any other

Digitized by Google

condition the approximate short circuit voltage can be found from the brush curves if due allowance is made for the number of bars covered by the brush and for any voltage assisting commutation due either to interpole flux or to the main flux in non-interpole machines if the brushes are shifted into an active field at no load.

In regard to saturation in the interpole circuit, Curves *a*

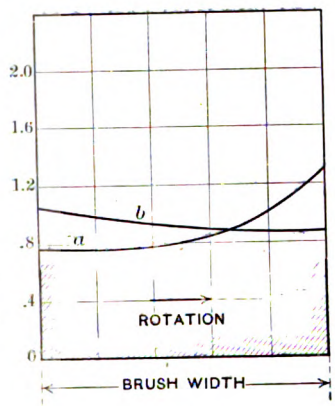


FIG. 3

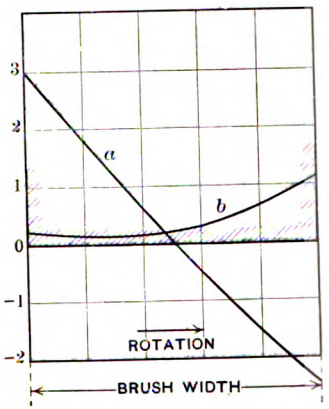


FIG. 4

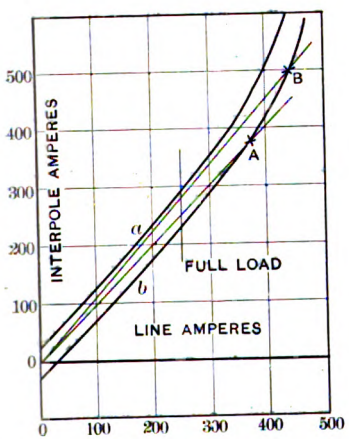


FIG. 5

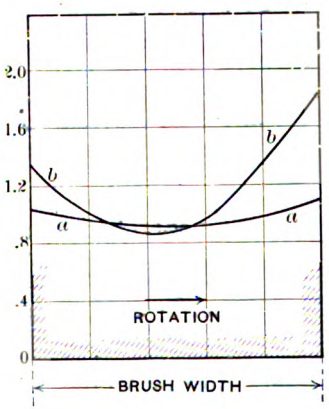


FIG. 6

and *b* shown in Fig. 5 are of special interest. They show the limits of sparkless commutation on a 62½-kw., 250 volt generator. This machine with flat compensation will begin to spark at 1½ load (point *A*), while with over-compensation it will not spark until 1¾ load (point *B*) is reached. This shows very clearly why an interpole machine should be over-compensated. Fig. 6 shows the brush curves taken on this same machine at

Digitized by Google

full load, Curve *a*, and 1½ load, Curve *b*. Curve *b*, of course, shows under-compensation.

In a series or heavily compounded motor, saturation is even more serious than it is in a shunt machine, for that part of the magnetic circuit common to the main pole and interpole saturates as the load comes on. Fig. 7 shows the brush curves for a 5-h.p. heavily compounded motor, 1260 rev. per min., 5.25 amperes (Curve *a*), and at 813 rev. per min., 20 amperes, (Curve *b*).

Curve *a*, Fig. 8 shows another way of representing the saturation of the interpole circuit. It represents the resultant voltage between bars at the center of the brush for various armature currents in a series motor operating at constant speed. This 160-h.p. motor, on account of the conditions of the service required of it, is necessarily highly saturated. The dotted line *b* gives the over-compensation which would be obtained if there

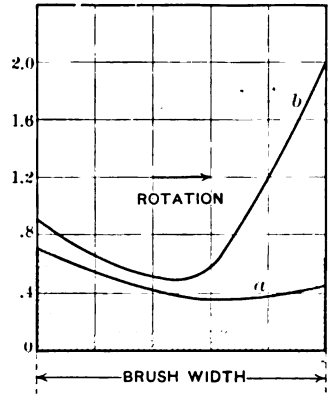


FIG. 7

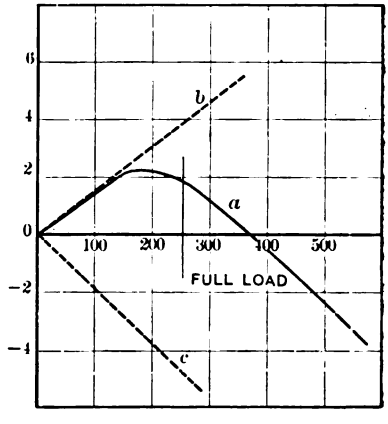


FIG. 8

were no saturation in the interpole circuit, while the dotted line *c* gives the approximate short circuit voltage of the commutating coil. This curve shows clearly the special importance of over-compensation in the case of series motors which are required to operate at large overloads for short periods of time.

The importance of properly shaping the interpole face, as explained by Mr. Lamme, is clearly shown by the brush curves in Fig. 2. Curve *a*, while it shows flat compensation, also shows current peaks at both sides of the brush. The effect is caused by too wide an interpole face and too small an interpole gap. When the interpole covers more than one slot pitch and the period of commutation does also, the increased flux density under the edges of the interpole will give a brush curve similar to Curve *a* in Fig. 2. Curve *b* shows this effect much reduced due to the shortening of the period of commutation, and, while it shows under-compensation, the current density at the leading

Digitized by Google

brush tip is apparently less than in the case of Curve *a*. A machine with a brush curve like *a* is, of course, sensitive to interpole adjustment, brush setting, sudden changes of load, " etc ". It thus seems to be well worth while to so fashion the interpole face that good brush curves and approximately equal distribution of current under the brushes may be obtained.

B. G. Lamme: I have been much interested in the various points brought up in the discussion of the paper. There seems to be a general misunderstanding in regard to what is covered in this theory of commutation. This theory was intended to include only the internal actions involved in the operation of commutation and was not intended to cover extraneous conditions, such as undercutting of mica, quality or grade of brushes, type of brush holder, peripheral speed of commutator, etc. These features have largely to do with the mechanical conditions of commutation and, while they might be rightly classified under the broad subject of commutation, yet they do not belong to the theory as I have presented it. The undercutting of the mica, for instance, does not directly improve the commutating characteristics but it allows the brush to maintain more intimate contact with the copper surface of the commutator, at all times, than would be the case where the mica is not undercut. In the same way a good brush holder will maintain a more uniform contact and will prevent jumping and chattering of the brushes. The grade of brush will have a direct influence on the commutation, through its resistance, but the action of the brush is also mechanical, to a certain extent, as some brushes will give much smoother " riding " action on the commutator than others. The peripheral speed of the commutator face has considerable to do with the operation of the machine, through the operation of the brushes which ride on the commutator surface. However, these conditions do not modify the theory of the internal actions which take place in the armature during commutation.

A number of statements have been made this evening, to the effect that it should not be assumed that the method of analysis shown in this evening's paper will enable a beginner, or inexperienced person, to design good commutating machines. It was not the intention to create any such impression. A more careful perusal of the paper should call attention to the fact that, throughout, I have stated repeatedly that judgment and experience are required to use the method accurately. In fact, instead of making the problem appear simpler than formerly, in my mind, this method of analysis makes the problem appear more complex, for more conditions are included than in the usual methods of analysis, and at the same time these conditions have been shown to be extremely variable for different types of apparatus. In applying this method of analysis to non-interpole machines, for instance, the results obtained in many cases show that it is surprising that such machines have been made to work as well as they do. In fact, had this method been applied to

Digitized by Google

any great extent in the past, I am inclined to think that many non-interpole machines now in existence would never have been undertaken, as their commutating characteristics would have appeared so questionable.

One direct consequence of the use of this method of analysis, in the author's own experience, has been to dispel a former notion that interpole machines were more sensitive, or more "delicate", in some ways than the non-interpole type. After long experience in the analysis of the various types of machines, the conclusion was reached that interpole machines work surprisingly well, considering some of the badly proportioned machines which have been put on the market in the past by various manufacturers.

Taking up in order some of the points brought up at the discussion this evening—Mr. Erban has evidently misread the paper when he intimates that I said that little has been done to determine the permissible overload, without flashing, at the time of short circuit. I did not intend to give any such impression, but did intend to give the idea that it is impracticable to build large, high speed machines, especially for the higher voltages, which could be dead-short-circuited without flashing, and I attempted to show in a simple way why certain limits could not be exceeded. I judge that his experience, as to the limiting load possible without flashing, coincides very closely with my own.

As to the presence of conducting gas or vapor assisting or causing flash-overs, I agree entirely with him, but it should be kept in mind that this vapor is not the initial cause of the flash but is a means for spreading it. The real cause lies in the excessive short circuit voltage under the brush due to the excessive armature current at the moment of short circuit, as explained in the paper.

Mr. Hoxie takes exception to my statement that field distortion has no effect on the commutation. His contention appears to be that, when there is saturation, the distortion of the main field flux has a direct influence on commutation. But this is the one exception I made to my broad statement, for I showed in Fig. 17, and the accompanying text, why a saturated main pole, with a consequent heavy series winding, tended to give, to some extent, the effect of an interpole.

Mr. Hobart brings up the point that, with a non-interpole machine, without lead at the brushes, this method of calculation might give very good results, but that when lead was considered it was hopelessly involved. I do not agree with him that the method is an impossible or impracticable one in this latter case, for it has been tried out, in many cases, with very enlightening results. In that method of direct current machine design in which the magnetic "field form" or field distribution is used as the basis of the calculations, this method comes in naturally and is simpler to apply and gives a better insight of the problem than taking the resultant of the magnetomotive forces instead of fluxes.

Digitized by Google

Mr. Hobart has also suggested that the maximum voltage between commutator bars should be given consideration as this may lead to commutation trouble. I do not see wherein either the average or the maximum voltage between bars has anything to do with the direct problem of commutation, but I do agree with him that it is the maximum voltage which we should consider in the design of the machine, instead of the average voltage. The sparking or flashing troubles caused by too high a maximum voltage between bars do not originate under the brush as a rule, but start between those commutator bars which are connected to conductors cutting the maximum field flux. I would define this as commutator, rather than commutation, trouble.

Professor MacLaren has called attention to the fact that while the e.m.f. due to the interpolar flux is increased due to chording, yet the increase is not very large. He is correct in this. The point which I intended to bring out in my paper was that chording was harmful rather than beneficial as far as the interpolar flux is concerned, and possibly the proportions shown in Fig. 4 in the paper, gave an exaggerated idea of this effect.

He also states that in working out certain large machines according to this method of calculation he found that the e.m.f. due to the interpolar flux in some cases was much greater than the e.m.fs. due to the slot and end fluxes. This appears to me to be rather unusual, in the ordinary type of machine, although I can see that if extra precautions were taken to reduce the e.m.fs. due to the slot and end fluxes, while none were taken to reduce the e.m.f. due to the interpolar flux, it might be possible to get the latter relatively high. Professor MacLaren also suggests that the effect of the chording on the slot e.m.f. as given in the paper, is greater than experience indicates. However, in many cases, especially where the end and interpolar fluxes are high, the effect of the chording would be relatively small, in the total result. In the example which he mentions, in which the e.m.f. due to the interpolar flux was 2.8 volts, that due to the end flux was 0.9 volts, while that due to the slot was 1.3 volts, it is obvious that a considerable variation in the latter value, due to the chording, would have a comparatively small effect on the total result. The influence of chording, as indicated in this paper, agrees very well with my own experience.

Professor Adams has called attention to the fact that the method of analysis given in the paper does not cover instantaneous conditions during the operation of commutation. I admit that there are small high frequency disturbances which occur periodically within the period of commutation, but these disturbances repeat themselves within a cycle of one tooth pitch, while in the method of calculation shown in the paper the results are averaged over one tooth pitch. The period of commutation is very seldom as short as that represented by one tooth pitch and is usually considerably longer. Therefore, in practice, the minor disturbances occur only in a relatively small

Digitized by Google

part of the period of commutation. But even if we did calculate these disturbances with any accuracy, we could not use the results in our calculations for interpole machines, for it is only the average voltage which we can compensate, or it is only the average short circuit e.m.f. which the interpole neutralizes. While such minor disturbances may be interesting from a purely theoretical standpoint, yet in a practical design they need not be taken into account and, in fact, they may be, to a certain extent, suppressed by damping action in the interpole and elsewhere.

Professor Adams also calls attention to the possibility of secondary currents in the short circuited coils, set up by pulsations in the main field flux due to changing magnetic reluctance in the main circuit, as the armature rotates. This effect may be present, to a certain extent, and, if of materially large value, it would be harmful. However, this is an effect which the designer aims to eliminate, or to reduce to a low value for other reasons than commutation and, in well designed machines, it should have but very little influence on the commutation. In fact, I do not recall any instances in machines of recent design in which this effect has been sufficient to give any noticeable trouble.

Mr. Burke brings up a number of points which have been covered, to some extent, by what I have already said. He calls attention to the fact that certain machines operate in a satisfactory manner which, according to the ordinary calculations, should not be good operative machines. I have noted similar cases. As a rule, these cases have to do with machines for intermittent service, reversing machines, etc. In such machines, commutation characteristics appear to be allowable which are not at all permissible in ordinary continuous service. In fact, non-interpole railway motors without any lead at the brushes are, in many cases, operative at voltages across the brush, or between adjacent commutator bars, which would seem to be prohibitive. In fact, they would be prohibitive if it were not for the intermittent load and other special conditions of operation.

Mr. Burke has referred to a method of finding the true interpole commutating position, and he refers to adjustments which are departures from this position, in order to obtain more suitable conditions. I agree with him that it is very important to find the theoretically correct position of the brushes in interpole machines, but I think that it is wrong, especially in generators which are to operate in parallel, to permit any appreciable departure from this correct setting; for other troubles than commutation are liable to be encountered if the brushes are not set at the true neutral.

Mr. Burke has referred to a special arrangement of interpole which, in his opinion, may have some advantage over the usual type. The type of interpole he shows is not a new one to me,

Digitized by Google

for an experimental machine of this type was designed by one of my associates several years ago. The arrangement is operative, but it seems to me that it is not a very practical scheme. Mr. Burke is somewhat in error in the figures which he gives for the advantages in this arrangement. For example, he assumes 10,000 ampere turns per pole in the armature and an excess of 2,000 to 4,000 ampere turns in the interpole, or say, 3,000 ampere turns excess. With the arrangement of interpole which he has shown he considers that the armature opposing ampere turns may be reduced to 1,500, instead of 10,000. The total ampere turns on the interpole then become 1,500 plus 3,000 =4,500. But he overlooks the return path required for the interpole flux and, assuming this to be of practically the same section as the interpole, 3,000 ampere turns additional are required for the gap in the return path. The total thus becomes 7,500 ampere turns, compared with 13,000 ampere turns with the usual type. This would be but little better than the interpole arrangement with half as many interpoles as main poles. However, a marked disadvantage in this scheme lies in the extra space required for the interpole. With the usual arrangement of interpole it is frequently difficult to find space for the interpole without reducing the effective circumferential width of the main poles. With this proposed arrangement the space for the special interpole would have to be increased very materially in most cases, and I believe that the decrease in output, due to such reduction in the width of the main poles would far more than balance the possible gain.

Mr. Treat has called attention to what he considers an apparent error in the derivation of the formulæ. He states that in connection with Fig. 10, " The author appears to assume that the e.m.f. developed in the conductor depth d by this flux is proportional to $\frac{1}{2}\,d$. Extensive experiments have shown that the e.m.f. curve for the conductor of depth d will take the form of a parabola and the average e.m.f. is proportional to $\frac{1}{3}\,d$."

Evidently Mr. Treat has not gone carefully into the derivation of the formulæ given in connection with this point, or he would have seen that the actual value used is in proportion to $\frac{1}{3}\,d$ instead of $\frac{1}{2}\,d$. The result obtained is therefore in accordance with his experience in this point.

He also states that he has not been able to verify the factor $0.54\times\sqrt{n}$, which represents the flux from the tooth top and that, according to his calculations, the expression should be a logarithmic function of certain slot and surface dimensions. In reply to this I will say that, as worked out originally, this was a logarithmic function, but the expression was unduly complicated and was replaced by the simpler expression given in the paper, which is an equivalent within the practical range of design. Furthermore, a slight discrepancy in this part has such a small effect on the total result that it was considered advisable to use the simpler expression throughout.

Digitized by Google

I feel that the discussion of the paper has been hampered, to a certain extent, by the delay in its issue. A number of the statements made this evening have obviously been due to insufficient opportunity to go into the paper thoroughly, for a number of points which have been raised are, in reality, covered in the paper itself. In a number of cases I have not called attention to these, for I believe that more careful reading of the paper will furnish the answer to these points.

Digitized by Google

KERITE

INSULATED WIRES & CABLES

Dependable

Kerite Cables installed upward of 35 years ago, and exposed to deteriorating influences, are giving perfect service today.

Efficient

Kerite does not rely upon the rubber in its composition for insulating efficiency. Kerite itself is a compound having superior insulating qualities.

Service

A half century of successful service has demonstrated that Kerite possesses the essential qualities of safety, reliability and economy to an exceptional degree.

Kerite Insulated Wire and Cable Co.

Incorporated by W. R. Brixey

General Offices:
Hudson Terminal, 30 Church Street, New York

Western Office:
Peoples Gas Building, Chicago

Digitized by Google

Electrical Testing Laboratories

Photometrical Department

Photometrical tests of all forms of commercial illuminants. Illumination tests made anywhere indoors or outdoors.

Electrical Department

Tests of electrical instruments, apparatus and materials. Inspection of electrical material and apparatus at factories.

General Testing Department

Coal and ash analysed. Paper tested. Industrial and clinical thermometers checked. Tensile, compression and torsion tests of structural materials. Complete tests on cement and concrete.

80th STREET and EAST END AVENUE
NEW YORK, N. Y.

TRANSACTIONS WANTED

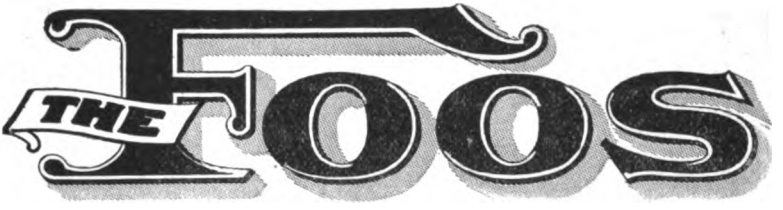
The following volumes of the Institute Transactions are needed to complete sets.

Volume I	(1884)
Volume III	(1886)
Volume V	(1888)
Volume VI	(1889)
Volume VII	(1890)
Volume IX	(1892)
Volume XVII	(1900)
Volume XVIII	(1901)

Members in possession of any of the above volumes in good order, who may wish to dispose of same, kindly communicate with

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Digitized by Google



THE FIRST AMERICAN ENGINE TO DEVELOP A "BUILT IN" MAGNETO

This development in the Standard Foos Engine is obtained with mechanical simplicity and durability and a higher electrical efficiency than with batteries. The Magneto is "built in" the engine and operated positively by gears. It runs at engine speed and is used for starting and operating to the entire exclusion of batteries. The electrical results embrace a thick, hot, dynamic spark even while the armature is revolving very slowly in turning the flywheels of a large engine by hand. Full information concerning this Magneto and the advantages obtained by its use in connection with Foos Gas and Oil Engines will be sent on request for Bulletin M-95.

THE FOOS GAS ENGINE COMPANY

509 LINDEN AVE. SPRINGFIELD, O.

ALPHABETICAL LIST OF ADVERTISERS.

	PAGE.
Allis-Chalmers Co.	xvi and xxiii
Arnold Co., The	iv
Arnold, Bion J.	iv
Baldwin Locomotive Works	xxiv
Barstow & Co., W. S.	iv
Bates, Putnam A.	iv
Baum, F. G. & Co.	iv
Byllesby & Co., H. M.	iv
Clayton & Craig	iv
Clement, Edw. E.	iv
Crocker-Wheeler Co.	xxi
Cutler-Hammer Mfg. Co.	xiv
Electrical Testing Laboratories	ii
Elec. Testing & Research Laboratory	iv
Electro-Dynamic Co.	
Electrose Mfg. Co.	xv
Fort Wayne Electric Works	xx
Foos Gas Engine Co.	iii
General Electric Co.	Inside back cover
Goulds Mfg. Co.	xix
Gurley, W. & L. E.	viii
Hill, Nicholas S., Jr.	iv
Howson & Howson	v
Jackson, D. C. & Wm. B.	v
Jones Co., Fred A.	v
Kerite Insulated Wire & Cable Co.	i
Lincoln, E. S.	iv
Marshall, Wm.	v
Minerallac Electric Co.	xvii
Moloney Electric Co.	xii
National Brake and Elec. Co.	xix
Neall, N. J.	v
Pierce, Richardson & Neiler	v
Rensselaer Polytechnic Institute	vii
Roebling's Sons Co., Jno. A.	Back cover
Rosenbaum & Stockbridge	v
Sanderson & Porter	v
Sargent & Lundy	v
Smythe, Edwin H.	vi
Sprague Electric Co.	xx
Sprague, Frank J.	vi
Standard Underground Cable Co.	xvi
Stanton, LeRoy W.	vi
Stone, John Stone	vi
Stromberg-Carlson Telephone Mfg. Co.	xxi
Syracuse University	vii
Thomas, P. H.	vi
Thompson, Edw. P.	vi
Townsend & Decker	vi
Van Nostrand Co., D.	Inside front cover
Wagner Electric Mfg. Co.	xvii
Western Electric Co.	xxii
Westinghouse Electric & Mfg. Co.	xxiv
Westinghouse Machine Co.	
Westinghouse Traction Brake Co.	xxiii
Weston Electrical Instrument Co.	x
White & Co., J. G.	vi
Zabel, Max W.	vi

(For Classified List of Advertisers see page IX.)

Digitized by Google

THE ARNOLD COMPANY

Engineers,
Constructors.

Electrical - - Civil - - Mechanical.

105 So. La Salle Street, Chicago.

W. B. CLAYTON JAS. W. CRAIG

CLAYTON & CRAIG

Incorporated

Electrical and Mechanical Engineers

Tel. Oxford 3788

161 Summer St. Boston, Mass.

BION J. ARNOLD,

Member A. I. E. E.

Consulting Electrical Engineer

105 So. La Salle Street, Chicago
154 Nassau Street, New York

H. M. BYLLESBY & CO.

Engineers

206 South La Salle Street, Chicago
Portland, Oregon

W. S. Barstow & Company

Incorporated

ENGINEERS - CONSTRUCTORS MANAGERS

50 Pine Street, New York
Spalding Building, Portland, Ore.

EDWARD E. CLEMENT,

Associate A.I.E.E.

Attorney and Expert in Patent Causes.

Soliciting, Consultation, Reports, Opinions.

McGill Bldg., Washington, D. C.

PUTNAM A. BATES,

Member A.I.E.E.

Consulting Electrical Engineer,

2 Rector Street, New York.

Electrical Testing and Research Laboratory.

Facilities for investigating any branch of the electrical industry Designs. Reports, Specifications, etc.

E. S. LINCOLN,
Consulting Engineer,
Brookline, Mass.

F. G. BAUM & COMPANY

Engineers and Constructors

Examinations, Reports, Estimates
Designs, Complete Hydro-Electric
Power Developments, Electric Power
Transmission Systems
Dams and Irrigation Systems

1404-7 Chronicle Bldg.
San Francisco, Cal.

NICHOLAS S. HILL, Jr.
Assoc. A.I.E.E.

Consulting Steam and Hydraulic Engineer

100 William Street New York City
Telephone 2053 John.

Water Supply, Sanitary and Water Waste Investigations, Fire Protection, Water Power Development, Industrial Power Plants, Pumping Stations, Steam Engine Economy

Digitized by Google

HOWSON and HOWSON,

Counselors at Law,

Solicitors of Patents,

55 Liberty St., New York,
32 S. Broad St., Philadelphia,
918 F. St., Washington, D. C.

PIERCE, RICHARDSON & NEILER
(Incorporated)

ENGINEERS

Consulting, Designing and Supervising

Manhattan Building - - Chicago

D. C. & WM. B. JACKSON

Consulting Engineers for Electric and Allied Properties

CHICAGO **BOSTON**
Harris Trust Bldg. **84 State Street.**

William A. Rosenbaum
William M. Stockbridge

Alfred Waters Proctor
Delos Holden

ROSENBAUM & STOCKBRIDGE
Patent Attorneys

Telephones { 7524 / 7525 } Cortlandt

41 Park Row **New York City**

THE FRED A. JONES CO.,

Engineers,

Houston, Texas
Chronicle Building
Dallas, Texas
Scollard Building
New Orleans, La.
Hibernia Bank Building

SANDERSON & PORTER
ENGINEERS AND CONTRACTORS
REPORTS **DESIGNS**
CONSTRUCTION **MANAGEMENT**
HYDRO-ELECTRIC DEVELOPMENTS
RAILWAY, LIGHT AND POWER PROPERTIES
NEW YORK SAN FRANCISCO

WILLIAM MARSHALL,
Electrical Engineer,

Marshall's Electrical Condensers For Telegraph, Telephone, Electric Light X-Ray, Experimental and Wireless Systems

Sending Condensers for Wireless made to stand any voltage required. Standard Condensers a specialty. These Condensers are used in all Telegraph offices in America where Standard and ordinary Condensers are required. Condensers and Artificial Lines for Submarine Cables and Land Lines. Send for Catalogue.

709 Lexington Ave., near 57th St., New York

SARGENT & LUNDY

F. SARGENT } Members
W. S. MONROE } A.S.M.E.

A. D. LUNDY } Members
JAMES LYMAN } A.I.E.E.

Railway Exchange Bldg., Chicago

N. J. NEALL

OF

BOSTON.

Consulting Electrical Engineer.

Appraisals.

JESSE M. SMITH, M.E.

Member A.S.M.E.
Member A.I.E.E.

Consulting Engineer
Expert in Patent Causes

220 Broadway **New York, N. Y.**

Digitized by Google

EDWIN H. SMYTHE

Associate A.I.E.E.
Member W.S.E.

Expert in Patent Causes

Special attention to cases involving Telephone and Electrical Patents

738 Monadnock Bldg. - Chicago

EDWARD P. THOMPSON, M.E.
Registered Patent Attorney,
Victor Bldg., Washington, D.C.
34 East 32d St., New York

Pat. Atty., of formerly existing patent bureaus of *Electrical World* and *Power*. Charter member, and once a manager and examiner, and served 48 inventors of A I E.E. Secured 3 000 patent claims. Mail description of invention for free candid opinion and estimate to apply for patent Delay dangerous *Specialty:* business by mail with electrical inventors. Established 20 years

FRANK J. SPRAGUE,

Past President and Member,
Am. Inst. E. E.
N.Y. Elec. Soc.
Member,
A. Soc. C. E., Inst. E. E.
Inst. C. E., U. S. N. Inst.

Consultation - - Engineering
165 Broadway, New York.

TOWNSEND & DECKER
Solicitors of U.S. and Foreign Patents
Established 1880
(Attorneys at Law)
149 Broadway, New York

Henry C. Townsend, Ex-Chief Examiner Elec. Division. U.S. Patent Office
Chas. F. Tischner, Jr., M.E., Stevens Institute of Technology

LE ROY W. STANTON,

Consulting and Contracting Telephone Engineer.

Plans, Specifications and Supervision of Installation of Complete Telephone Plants. Special Reports on Telephone Properties and Apparatus.

901 Electrical Bldg., Cleveland, Ohio
1644 Monadnock Bldg., Chicago

J. G. WHITE & COMPANY,
Incorporated
Engineers, Contractors.

London Correspondent: J. G White & Co., Ltd, 9 Cloak Lane, Cannon St

43-49 Exchange Place, New York
First National Bank Bldg., Chicago, Ill.
Alaska Commercial Bldg., San Francisco, Cal.

JOHN STONE STONE

Consulting Electrical Engineer and Expert in Patent Causes

Reports on Inventions
Inventions Perfected
Expert Advice on Inventions

31 State Street, Boston **15 Gramercy Park, New York City**

MAX W. ZABEL, B.S.E.E.
Assoc. A.I.E.E
Patent Attorney

Patents, Trademarks and Copyrights
Expert Opinions and Investigations

1363 Monadnock Block, Chicago
Telephone, Harrison 4097

PERCY H. THOMAS

Consulting Electrical Engineer

Power Transmission
Design, Supervision, Advice
Lightning Protection
Special Investigations

2 Rector Street **New York**

YOUR CARD HERE

will bring you to the attention, each month, of the very men constantly in need of such services as you are prepared to give.
A limited number of these spaces (one-tenth page) are available for *professional* cards only
Address

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York City

Digitized by Google

EDUCATIONAL INSTITUTIONS.

POLYTECHNIC INSTITUTE OF BROOKLYN
New York City

Fred W. Atkinson, Ph. D., President

ELECTRICAL ENGINEERING COURSE.—A four years' course of study leading to the degree of Electrical Engineer, and offering exceptional facilities for acquiring a thorough practical, as well as theoretical knowledge of the science. By employing the splendid facilities of New York City itself as well as those of the Institute, the student is prepared to undertake at once the mastery of electrical problems and the control of electrical industries.

Graduates are everywhere occupying with honor positions of the gravest trust, many of which were obtained for them by the Institute, but in no section of the country are practical electrical engineers in greater demand than in New York.

ADVANTAGES OF SITUATION.—Students of the POLYTECHNIC INSTITUTE have placed at their disposal every advantage of the metropolis, itself a laboratory of invaluable utility. The variety and scope of practical operations open to inspection is of especial service; the kilowatt capacity of the city's central stations is greater than that of any other city in the world, Niagara Falls not excepted. Here may be studied the most modern methods for electric lighting, and for the generation, transmission, distribution and utilization of electric power.

For information apply to SAMUEL SHELDON, A.M., Ph.D.

SYRACUSE UNIVERSITY
Lyman Cornelius Smith College of Applied Science

Syracuse, N. Y.

Mechanical, Electrical and Civil Engineering. New buildings and approved equipment. Power plant. Usual shops. Complete hydraulic laboratory. Practical Chemistry.

Usual courses leading to degrees in Liberal Arts, also Medicine, Law, Architecture, Music, Painting, Pedagogy, Agriculture, Forestry, etc., in their respective schools. Send for catalogue.

RENSSELAER POLYTECHNIC INSTITUTE
TROY, N. Y.

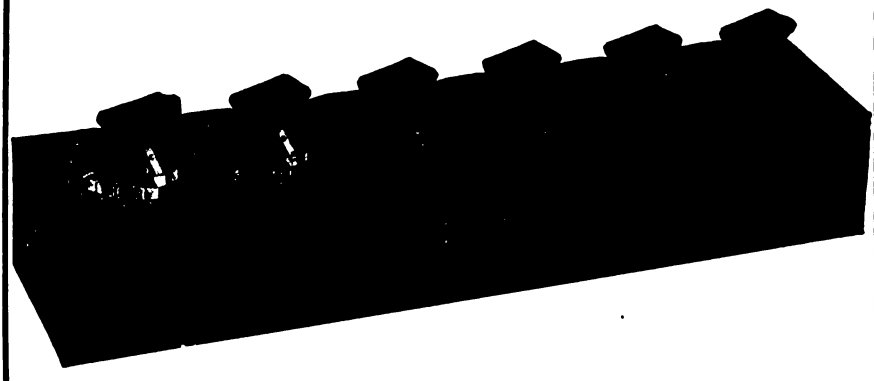
Courses in Civil, Mechanical and Electrical Engineering and Science, leading to the degrees C. E., M. E., E. E., and B. S.

The Russell Sage Laboratory for Mechanical and Electrical Engineering, equipped at a cost of $425,000, gives splendid advantages for practical experiments in Electricity and Mechanics. The Civil Engineering Laboratory contains machines for testing materials in Engineering up to 1,200,000 pounds capacity. Send for a catalogue to the Registrar.

DO THEY?

Do the consulting and contracting engineers, the chief engineers, superintendents, and other officers of lighting, railway, power, telephone and manufacturing companies know your products as well as you want them to? If not, do you know a better advertising medium for reaching these men than the PROCEEDINGS?

Digitized by Google



High Grade Resistances

made of manganin, wound on metal spools and with sliding contacts.

Any arrangement desired by the customer will be furnished.

Detailed information on request.

W. & L. E. Gurley

Troy, N. Y.

U. S. A.

Established 1845 ***Incorporated 1900***

Digitized by Google

The Institute Badge.

The Board of Directors has authorized the sale of Badges at the following prices, for the different styles.

Vest Pin,	**$3.00**
Scarf Pin,	**3.00**
Watch Charm,	**3.00**
Lapel Button,	**4.00**

All of the above patterns are of solid 14K gold and finely finished. The enamel is blue for Members and maroon for Associates. The initials or full name as desired, will be engraved on the back together with serial Number. Address,

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Classified List of Advertisers.

NOTE: For reference to the advertisements see the Alphabetical List of Advertisers on page III.

ACCUMULATORS, ELECTRICAL.
Electric Storage Battery Co., Philadelphia
Westinghouse Machine Co., East Pittsburg, Pa.

AIR COMPRESSORS.
Allis-Chalmers Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
National Brake & Electric Co., Milwaukee, Wis.
Westinghouse Traction Brake Co., New York

AMMETERS AND VOLTMETERS.
General Electric Co., Schenectady, N. Y.
Siemens & Halske A. G., 50 Church St., New York.
Wagner Electric Mfg. Co., St. Louis, Mo
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg Pa.
Weston Electrical Instrument Co., Newark, N. J.

ARRESTERS, LIGHTNING.
Anderson Mfg. Co., A. & J. M., Boston, Mass.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. and Mfg. Co. Pittsburg, Pa.

BATTERIES.
Electric Storage Battery Co., Philadelphia.

BOOKS.
Clayton & Craig, West Lynn, Mass.
Van Nostrand Co., D., New York.

BRAKES, CAR.
Allis-Chalmers Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
National Brake & Electric Co., Milwaukee, Wis.
Westinghouse Traction Brake Co., Pittsburg, Pa.

CIRCUIT BREAKERS.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Western Electric Co Schenectady, N Y
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co. Pittsburg, Pa.

CLUTCHES, MAGNETIC.
Cutler-Hammer Clutch Co., Milwaukee, Wis

(Continued on page XI.)

Digitized by Google

Weston

A COMPLETE LINE OF NEW

ALTERNATING CURRENT SWITCHBOARD INDICATING INSTRUMENTS

Comprising

WATTMETERS *Single and Polyphase*

May be used on circuits of any frequency from 15 cycles to 900 cycles per second without exhibiting error exceeding one per cent.
Practically free from error arising from changes in power-factor or wave-form, within the limits of practical work. Are therefore substantially equally accurate on A. C. or D. C. circuits.

POWER FACTOR METERS

Embody new and most ingenious features which render them the most accurate, durable and reliable instruments for use on either single or polyphase circuits.

SYNCHROSCOPES

Operate upon an entirely new principle. They are infallible in operation, and by their use all the difficulties and dangers involved in coupling alternating current machinery in parallel are overcome.

FREQUENCY METERS

Are also novel in their features of construction and operation. They have uniform and open scales and their indications are not affected by ordinary variations in wave-form or voltage.

AMMETERS and VOLTMETERS

These instruments are in extensive use and are now well known. Their external appearance has been changed slightly to harmonize with the other instruments in the new group.

This Entire Line of Instruments for Alternating Current Service is Fully Described in Our Catalog P. A. 16 Which will be Sent Upon Request.

Weston Electrical Instrument Co.

NEWARK, N. J.

NEW YORK	BOSTON	SAN FRANCISCO	BIRMINGHAM	MEXICO
CHICAGO	ST. LOUIS	CLEVELAND	MONTREAL	BERLIN
PHILADELPHIA	DENVER	NEW HAVEN	TORONTO	LONDON

Digitized by Google

Classified List of Advertisers—*Continued.*

(Continued from page IX.)

CONDUITS.
Fibre Conduit Co., Orangeburg, N. Y.
Sprague Electric Co., New York

CONTRACTORS.
Sanderson & Porter, New York.
White & Co., J. G., New York.

CONTROLLERS.
Crocker-Wheeler Co., Ampere, N. J.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Sprague Electric Co., New York.
Westinghouse Elec. and Mfg Co., Pittsburg, Pa.

CRANES AND HOISTS.
General Electric Co., Schenectady, N. Y.
Sprague Electric Co., New York

CUT-OUTS.
General Electric Co., Schenectady, N. Y.
Sprague Electric Co., New York.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

DYNAMOS.
See Generators and Motors.

EDUCATIONAL INSTITUTIONS.
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.
Rensselaer Polytechnic Institute, Troy, N.Y.
Syracuse University, Syracuse, N. Y.

ELECTRIC LOCOMOTIVES.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., Pittsburg, Pa

ENGINEERS.
Arnold, Bion J., Marquette Bldg., Chicago, Ill.
Barstow, W. S., 56 Pine St., New York.
Bates, Putnam A., 42 Broadway, New York, N. Y.
Baum, Frank G., Chronicle Bldg., San Francisco, Cal.
Byllesby & Co., H. M., New York Life Bldg., Chicago, Ill.
Hill, Nicholas S., Jr., 27 William St., N. Y.
Jackson, Dugald C. & W. B., Madison, Wis.
Jones Co., Fred A., 210 Main St., Houston, Texas.
Marshall, Wm., 709 Lexington Ave., New York.
Neall, N J., Boston, Mass.
Pierce, Richardson & Neiler, 315 Dearborn St., Chicago, Ill.
Sanderson & Porter, 52 William St., New York.
Sargent & Lundy, Railway Exchange Bldg., Chicago, Ill.
Sprague, Frank J., 20 Broad St., New York.
Stanton, LeRoy W., 1644 Monadnock Block, Chicago, Ill.
Thomas, P. H., 2 Rector St., New York.
White & Co., J. G., 43 Exchange Place, New York. N. Y.

ENGINES, GAS AND STEAM.
Allis-Chalmers Co., Milwaukee, Wis.
Hooven Owens Reutschler Co., Hamilton Ohio.
Westinghouse Machine Co., East Pittsburg Pa.

FANS, ELECTRIC.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Sprague Electric Co., New York.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

FIBRE.
Fibre Conduit Co., Orangeburg, N. Y.

GALVANOMETERS.
Weston Electrical Instrument Co., Newark, N. J.

GAS ENGINES.
Allis-Chalmers Co., Milwaukee, Wis.
Foos Gas Engine Co., Springfield, Ohio.
Westinghouse Machine Co., East Pittsburg, Pa.

GENERATORS.
Allis-Chalmers Co., Milwaukee, Wis.
Crocker-Wheeler Co., Ampere, N. J.
Fairbanks, Morse & Co., Chicago, Ill.
Fort Wayne Elec. Works, Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
National Brake & Electric Co., Milwaukee, Wis.
Sprague Electric Co., New York.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg Co., Pittsburg.

INSTRUMENTS, ELECTRICAL.
General Electric Co., Schenectady, N. Y.
Gurley, W. & L. E., Troy, N. Y.
Wagner Electric Mfg. Co., St Louis, Mo.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg Pa.
Weston Electrical Instrument Co., Newark, N. J.

INSULATORS AND INSULATING MATERIAL.
Anderson Mfg. Co., A. & J. M., Boston, Mass.
Electrose Mfg. Co., Brooklyn, N. Y.
General Electric Co., Schenectady N. Y.
Minerallac Elec. Co., Chicago, Ill.
Westinghouse Elec & Mfg Co Pittsburg, Pa
Western Electric Co., All Principal Cities.

LABORATORIES.
Electrical Testing Laboratories, 556 East 80th St., New York.

LAMPS, ARC.
Anderson Mfg. Co., A. & J. M., Boston, Mass.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co., Schenectady N Y.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.

(Continued on page XIII.)

Digitized by Google

MOLONEY HIGH EFFICIENCY TRANSFORMERS

100 per cent. value

Write for new Calalogue

MOLONEY ELECTRIC CO

Windsor, Ont. Canada — Office and Works — St. Louis, U.S.A.

STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

[Revised by the Standards Committee, and approved by the Board of Directors, June 27, 1911]

GENERAL PLAN.

I. Definitions and Technical Data.
- A. Definitions—Currents.
- B. Definitions—Rotating Machines.
- C. Definitions—Stationary Induction Apparatus.
- D. General Classification of Apparatus.
- E. Motors—Speed Classification.
- F. Definition and Explanation of Terms.

II. Performance Specifications and Tests.
- A. Rating.
- B. Wave Shaps.
- C. Efficiency.

III. Voltages and Frequencies.

IV. General Recommendations.

V. Appendices and Tabular Data.
- A. Notation.
- B. Railway Motors.
- C. Photometry and Lamps.
- D. Sparking Distances.
- E. Temperature Coefficients.

PRICE, 10 CENTS (Paper)———PRICE, 25 CENTS (Cloth)

PUBLISHED BY

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

33 WEST THIRTY-NINTH STREET, NEW YORK

Digitized by Google

Classified List of Advertisers—*Continued.*

(Continued from page XI.)

LIGHTNING ARRESTERS.
Anderson Mfg. Co., A. & J. M., Boston, Mass.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa

LOCOMOTIVES, ELECTRIC.
Baldwin Locomotive Works, Philadelphia, Pa
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

METERS, ELECTRIC.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa

MOTORS.
Allis-Chalmers Co., Milwaukee, Wis.
Crocker-Wheeler Co., Ampere, N. J.
Fairbanks, Morse & Co., Chicago, Ill.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
National Brake & Electric Co., Milwaukee, Wis.
Sprague Electric Co., New York.
Wagner Electric Mfg. Co., St. Louis, Mo.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

PANEL BOARDS.
General Electric Co., Schenectady, N. Y.
Krantz Mfg. Co., H., 160 7th St., Brooklyn, N. Y.
Western Electric Co. All Principal Cities.

PATENTS.
Clement, Edw. E., McGill Bldg., Washington, D. C.
Howson & Howson, 38 Park Row, New York, N. Y.
Rosenbaum & Stockbridge, 41 Park Row, New York.
Smythe, Edwin H., 738 Monadnock Block, Chicago.
Stitt Frederick S., 15 William St., New York, N. Y.
Thompson, Edw. P., 34 E. 32 St., New York.
Townsend & Decker, 141 Broadway, New York.
Zabel, Max W., 1362 Monadnock Block, Chicago

PUBLICATIONS, TECHNICAL
Appleton & Co., D., New York.
Science Abstracts, London, England.
Van Nostrand Co., D., New York, N. Y.

PUMPS
Goulds Mfg. Co., Seneca Falls, N Y.

RHEOSTATS.
Crocker-Wheeler Co., Ampere, N. J.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Gurley, W. & L. E., Troy, N. Y.
Sprague Electric Co., New York
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

SOLENOIDS, MAGNETIC.
Cutler-Hammer Mfg. Co., Milwaukee, Wis

STOKERS, MECHANICAL.
Westinghouse Machine Co., East Pittsburg, Pa.

STORAGE BATTERIES.
See Accumulators, Electrical.

SWITCHBOARDS.
Allis-Chalmers Co., Milwaukee, Wis.
Anderson Mfg. Co., A. & J. M., Boston, Mass
Bissell Co. The F., Toledo, Ohio.
Crocker-Wheeler Co., Ampere, N. J.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co. Schenectady N. Y.
Stromberg-Carlson Telephone Mfg. Co., Chicago, Ill.
Western Electric Co., All Principal Cities.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

TELEPHONES.
Stromberg-Carlson Telephone Mfg. Co., Chicago, Ill.
Western Electric Co., All Principal Cities.

TESTING SETS.
Foote, Pierson & Co., New York, N. Y.
Gurley, W. & L. E., Troy, N. Y.

TIME SWITCHES.
Albert & J. M. Anderson Mfg. Co., Boston.

TRANSFORMERS.
Allis-Chalmers Co., Milwaukee, Wis.
Crocker-Wheeler Co., Ampere, N. J.
General Electric Co., Schenectady, N. Y.
Moloney Electric Co., St. Louis, Mo.
National Brake & Electric Co., Milwaukee, Wis.
Wagner Electric Mfg. Co., St. Louis, Mo.
Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.

TRUCKS' STORAGE BATTERY AUTO.
Westinghouse Machine Co., East Pittsburg, Pa.

TUBING.
Fibre Conduit Co., Orangeburg, N. Y.

TURBINES, STEAM.
Allis-Chalmers Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities.
Westinghouse Machine Co., East Pittsburg, Pa.

TYPEWRITERS.
Remington Typewriter Co., New York.

WATTMETERS.
Fort Wayne Electric Works, Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Siemens & Halske A. G., 50 Church St., New York.
Westinghouse Elec and Mfg. Co., Pittsburg, Pa.
Weston Electrical Instrument Co., Newark, N. J.

WIRES AND CABLES.
General Electric Co., Schenectady, N. Y.
Kerite Insulated Wire & Cable Co., 30 Church St., New York.
Roebling Sons' Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburg, Pa
Stromberg-Carlson Telephone Mfg. Co., Chicago, Ill.
Western Electric Co., All Principal Cities

Digitized by Google

Cutler-Hammer
Crane Panels

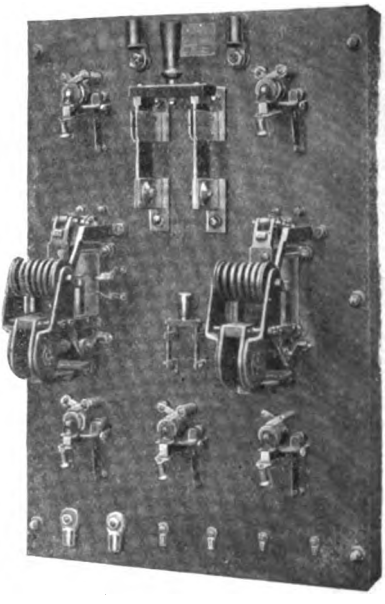
Provide Every Protection for the Motors

No fuses are required and the expense and delay of renewing them is eliminated. Yet every necessary protection against overload, short circuit and failure of voltage is provided for.

This panel simplifies installation and groups all switches, protective devices, etc., in one location. Safety switches prevent accidents when inspection or repairs are made.

Two single-pole standard mill type magnetic switches are used in the main line.

Our Engineers will advise you regarding your particular case. Write for further information.



Overload Crane Panel for three-motor crane.

Dynamic Braking, Drum Type
Crane Controllers

Cutler-Hammer New Crane Controllers are of the enclosed type. In a crane cab, accidents are liable with the open type controller and dust, dirt, etc., settle on the current carrying parts.

Cutler-Hammer Controllers insure against delays and accidents and permit of absolute control at all times. The working capacity of the crane per day can be increased.

Dynamic braking allows lowering the load under perfect control, even should the power fail.

New bulletin on Drum Crane Controllers on request.

The Cutler-Hammer Mfg. Co.
Milwaukee

Largest manufacturers of electric controlling devices in the world

NEW YORK: Hudson Terminal, 50 Church St. **PHILADELPHIA: 1201 Chestnut Street.**
CHICAGO: Peoples Gas Bldg. **PITTSBURG: Farmers' Bank Bldg.**
BOSTON: 176 Federal St. **CLEVELAND: Schofield Bldg.**
PACIFIC COAST AGENTS: Otis & Squires, 579 Howard St., San Francisco, 229 Sherlock Bldg., Portland, Ore., and W. B. Palmer, 416E. 3rd St., Los Angeles

Digitized by Google

TRADE
ELECTROSE
MARK.
REG. U.S. PAT. OFF. & FOREIGN COUNTRIES.

INSULATORS FROM 1000
TO 1000000 VOLTS

"SAFETY STRAIN"
DISK INSULATORS

SOLE MANUFACTURERS

ELECTROSE MFG. CO.
127 to 137 North 10th Street

LOUIS STEINBERGER'S PATENTS

Brooklyn, N. Y.
130 to 140 North 11th Street

Digitized by Google

Bare and Insulated

COPPER
WIRES and
CABLES

FOR ALL ELECTRICAL PURPOSES

Insulation of Paper, Fibre,
Rubber, Varnished Cloth

TERMINALS
JUNCTION BOXES

STANDARD UNDERGROUND CABLE CO.
PITTSBURGH

Boston New York Philadelphia Chicago St. Louis San Francisco

Do you wish to keep your name and business before the men who control purchases in the electrical industry? *A limited amount of advertising space is now available.* Rates will be sent upon application. Address:

American Institute of Electrical Engineers
33 West 39th Street, New York City.

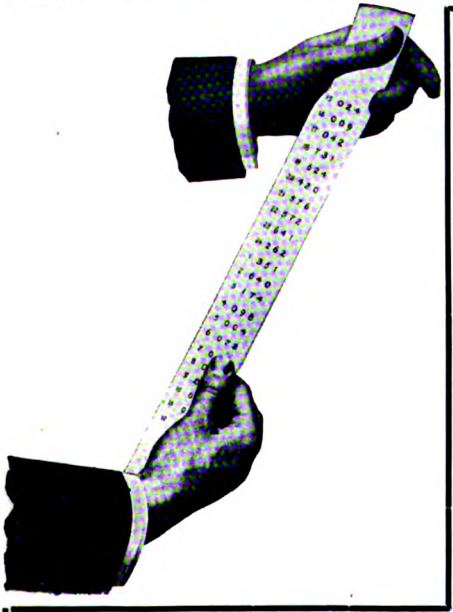
Digitized by Google

SINGLE-PHASE AND POLYPHASE MOTORS

WAGNER ELECTRIC MANFG. COMPANY
Wagner Quality
SAINT LOUIS, U.S.A.

TRANSFORMERS - - INSTRUMENTS - - A. C. GENERATORS - - A. C. RECTIFIERS

WRITE FOR BULLETINS



TO SECURE POWER BUSINESS

Use Up-to-date Methods of Measurement

The **CHICAGO PRINTING ATTACHMENT** is the only positively accurate instrument made with which the actual cost of energy can be determined absolutely instead of by approximation. It gives the most complete information about the maximum demand and is now being used in connection with the largest and most important power contracts in the world. It gives you a printed record in plain figures of the kilowatt-hour consumption during every five minute or longer interval of the entire twenty-four hours.

It gives you the maximum and the exact time it occurs.

Bulletin No. 45.

MINERALLAC ELECTRIC CO. :: Chicago, Illinois

Digitized by Google

A. I. E. E. PUBLICATIONS.

PROCEEDINGS. Published monthly. Contains two sections.

Section I is devoted to current Institute news, notices of meetings, reports of committees and of Section and Branch meetings, abstracts of lectures and papers presented at Section and Branch meetings, special contributions, personal mention, etc.

Section II contains all of the technical papers and discussion presented at regular Institute Meetings, reports of various technical committees of the Institute and other matters of an engineering character.

Annual subscription price in the United States $10 00
All other countries 12 00
Single copies 1 00
Discount to members of the A. I. E. E. and to libraries, 50 per cent.
Discount to Publishers, Agents and Dealers, 10 per cent.

TRANSACTIONS. Published annually.

Contains such of the technical papers, discussions and reports published in the PROCEEDINGS as are selected and authorized by the Meetings and Papers Committee of the A. I. E. E. The TRANSACTIONS form a permanent record of the progress of electrical engineering.

Existing bound volumes may be purchased by non-members at the following prices:
Paper covered volumes, per year $10 00
Cloth " " " " 11 50
Half Morocco " " " 13 00

A discount of 10 per cent from the above prices, either for volumes, subscriptions, or parts, may be allowed to publishers and dealers. Members and Associates shall be allowed a discount of 50 per cent on parts or duplicate volumes to replace those lost or destroyed. They may purchase volumes issued prior to their election, when available, at $5.00 each, either in paper or cloth covers. Add $1 00 for each volume or part in half morocco binding. See page 2 for list of volumes issued in two parts.

STANDARDIZATION RULES. Revised Edition, Published 1911.

Gives standard definitions of electrical terms, technical data, standard performance specifications and tests of electrical machinery, standard voltages and frequencies, and general recommendations, as adopted by the Standards Committee and approved by the Board of Directors of the A. I. E. E. June 27, 1911.

Price per copy (paper) $0.10
(discount on quantities)
" " " (cloth) 0.25
(net)

CATALOGUE OF THE WHEELER GIFT. Published 1909.

A bibliographical catalogue of the celebrated Latimer Clark collection of books, pamphlets and periodicals presented to the Institute, by Schuyler Skaats Wheeler. This catalogue was in preparation for seven years under the direction of Mr. W. D. Weaver in collaboration with Brother Potamian, of Manhattan College, and a number of other authorities in America and abroad. It has a distinct educational value, as its pages reveal the evolution of electrical science, and arts, and the reader can form at least a passing acquaintance with the monuments of electrical literature.

Two volumes, 8vo. cloth. Numerous illustrations. Price per set, net $8.00

YEAR BOOK OF THE A. I. E. E. Published annually in January.

Containing lists of Officers, Board of Directors, Committees, Members, Associates, and Enrolled Students; Sections and Branches; Constitution, By-laws, and general information regarding the scope and work of the Institute.

Price per copy $0.50
Free to members.

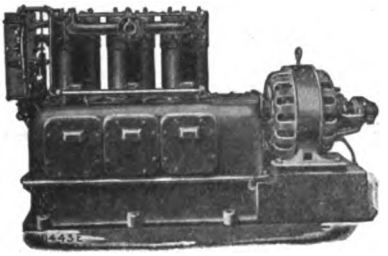
COPPER WIRE TABLE. Published 1893.

Gives weights, lengths and resistances of cool, warm and hot wires of Matthiessen's standard conductivity for both American and Birmingham wire gauges.

Price per copy $0.10

Digitized by Google

National Air Compressors



150 Cu. Ft. "3VS" Type Air Compressor with A. C. Motor and Combined Automatic Controlling Apparatus.

Type "3 VS."

These compressors are designed for general industrial service. They are of the single stage type, are very compact and are built to stand hard service and usage. Either direct or alternating current motors can be furnished to operate same. Built in capacities of 50, 100, 150, 225 and 300 cu. ft. of free air per minute.

Write for Publication 87B.

National Brake & Electric Co.
Milwaukee, U. S. A.

New York, 165 Broadway
Chicago, 1344 First National Bank Building
Pittsburg, 9th and Penn Ave.
St. Louis, 405 Security Building
London, England, 14 Great Smith St.

Goulds Triplex Plunger Pumps

are made in all capacities
for every class of pumping service

Our line also includes centrifugal and rotary power pumps, air compressors, working heads—everything needed in pumping service.

Put your pumping problems up to us. We give you the benefit of over half a century of experience.

THE GOULDS MFG. CO.

110 West Fall St., Seneca Falls, N. Y.
16 Murray St., New York
58 Pearl St., Boston
Branches in all large cities

Digitized by Google

FORT WAYNE

Every Electrical Engineer

Should be posted on Electrical Apparatus and know who makes the best kinds for different purposes.

Perhaps it's not possible for you to visit our factories but we want you to become familiar with our products.

We make a specialty of manufacturing Complete Equipments for Light and Power Stations

Our Meters, Alternators, Generators, Transformers, Switchboards, Motors, etc , are used in some of the finest installations all over the country and have established for us a national reputation for quality

We won't attempt here to tell all their strong points; their exclusive advantages—the features that make them superior to others or show why they last longer, do their work better and require fewer repairs, but we have some interesting illustrated Bulletins on each subject that go into details on these points.

These bulletins are free and we will be glad to furnish you with any you desire.

Fort Wayne Electric Works

OF GENERAL ELECTRIC COMPANY

MAIN OFFICE: Fort Wayne, Ind. FACTORIES: Fort Wayne, Ind., and Madison, Wis.

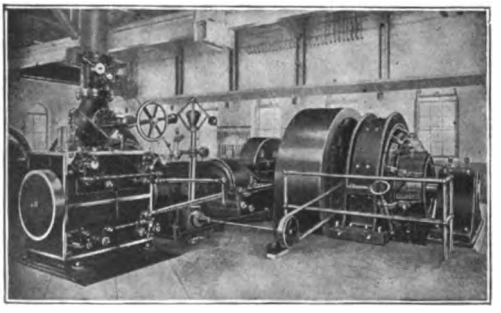
SALES OFFICES:

Atlanta			Seattle
Boston	Dallas.	Milwaukee	St. Paul
Charlotte	Denver	New York	St. Louis
Chicago	Grand Rapids	New Orleans	San Francisco
Cincinnati	Kansas City.	Pittsburg	Syracuse
Cleveland	Madison	Philadelphia	Yokohama, Japan

SPRAGUE ELECTRIC

TWO- AND THREE-WIRE

GENERATORS



Sprague Electric 400 Kw Generator
In Plant of Standard Bleachery Co . Carlton Hill, N. J.

Direct Current
Advanced Construction
High Efficiency

The excellent design and careful construction of Sprague Electric Generators make them the ideal installation for industrial plants, hotels, apartment houses, office buildings, etc. They are unsurpassed in efficiency, regulation and durability.

Write for Descriptive Bulletin No. 11021

SPRAGUE ELECTRIC WORKS

OF GENERAL ELECTRIC COMPANY

Main Offices: 527-531 West 34th Street, New York City
Branch Offices in Principal Cities

Digitized by Google

CROCKER-WHEELER
TRANSFORMERS

One of the lighting companies tested all the transformers on the market. As a result they found the "**REMEK**" far ahead, and ordered a full equipment of "**REMEKS**". The table shows the result of this test.

The numbers 1, 2, 3 and 4 represent the 4 transformers coming the nearest to the Remek in efficiency.	Exciting Current, Amps.	Core Loss, Watts	Resistance in ohms		Full Load Copper Loss in Watts at 239 Volts			Core and Copper Loss	Total Full Load Loss by Wattmeter	Regulation in % at Unity P. F.
	At 239 Volts on secondary		Pri.	Sec.	Pri.	Sec.	Total			
Crocker-Wheeler "Remek" 15 KVA—2400/240-120	0.95	84.0	2.335	.02745	91.80	107.80	199.60	283.60	295.00	1.34
No. 1—15 KVA— 2400-1200/240-120	0.90	90.0	2.529	.0283	99.30	111.50	210.80	300.80	312.80	1.42
No. 2—15 KVA— 2400-4800/240-120	1.28	118.8	2.148	.02999	84.40	117.50	201.9	320.70	331.70	1.35
No. 3—15 KVA— 2400-1200/240-120	2.80	131.0	2.631	.02486	103.50	97.80	201.30	332.30	344.00	1.3[illegible]
No. 4—15 KVA— 2400-1200/240-120	1.75	108.0	2.963	.0274	116.60	10780.	224.40	332.40	344.40	1.51

CROCKER-WHEELER COMPANY

AMPERE, N. J. Branches in principal cities.

The Largest Independent Manufacturers of

TELEPHONE APPARATUS

Aerial and Underground Cable

TELEPHONES for any kind of service SWITCHBOARDS for any size system

Mine-A-Phones—Inter-Comm-Phones—Dispatchers' Signal Systems—Railway Telephones—Deffones—Combination-Phones—Telephone Supplies of All Kinds

The Most Modern Equipment of Unexcelled Quality

Consult us regarding any telephone requirement

No orders are too large to overtax our capacity or too small to receive our best attention

Stromberg-Carlson Telephone Mfg. Co.

Rochester, New York, U.S.A.

Chicago, Ill. **Toronto, Canada** **Kansas City, Mo.**
Los Angeles, Cal. **San Francisco, Cal.** **Seattle, Wash.**

Digitized by Google

Your Department at Your Finger's End

Western-Electric
TRADE MARK
Inter-phones

afford you instant and reliable communication with all departments — and with each other. Just push the button and talk — no delays and misunderstandings of the messenger boy.

No needless inter-department visiting. Each station a complete switchboard — all stations call from any other.

Furnished in sizes from 2 to 24 stations.

Purchase Price Reasonable.

Operating Cost Trivial.

Bulletin No. 950. will give you details.

WESTERN ELECTRIC COMPANY

Manufacturers of 6,000,000 "Bell" Telephones

New York	Cincinnati	Omaha
Buffalo	Minneapolis	Oklahoma City
Philadelphia	St. Paul	San Francisco
Boston	Milwaukee	Oakland
Pittsburg	Saint Louis	Los Angeles
Atlanta	Kansas City	Seattle
Chicago	Denver	Salt Lake City
Indianapolis	Dallas	Portland

Montreal London
Toronto Berlin Paris
Winnipeg Johannesburg
Vancouver Sydney
Antwerp Tokyo

Address the house nearest you.

EQUIPMENT FOR EVERY ELECTRICAL NEED

Digitized by Google

Repeat Orders--
A Proof of
"Quality"

Repeat Orders are the result of satisfaction to the customer not only after the first purchase, but entire satisfaction after every purchase.

Repeat Orders are the life of a manufacturer—they have a cumulative effect.

Repeat Orders are proof positive of the maintenance of a high standard of manufacture.

Repeat Orders are a feature of the business of Allis-Chalmers Company and one of its biggest assets.

Repeat Orders for Allis-Chalmers machinery are coming from your neighborhood. Ask any user in your vicinity why he specifies this company's apparatus, and receive positive assurance of its quality.

Allis-Chalmers Company

General Offices :: Milwaukee, Wisconsin

Offices in all Principal Cities

Electro-Pneumatic Brakes
For Subway and Elevated RR. Service

With the purely pneumatic brake system developed to the greatest extent, concentration of large populations in limited areas has created a further demand for increased safety, greater reliability, reduction in time to make service stops, and instantaneous response and uniform application of brakes, whereby the human factor in manipulation can be reduced to a minimum.

All these demands are met by the addition of electric control to the service and emergency functions of the pneumatically operated quick-action automatic brake.

The electro-pneumatic brake system adds to the pneumatically-operated brake of the highest type the following advantageous features otherwise impossible of attainment, namely:

(a) Simultaneous and uniform response of all brakes in a train. This practically eliminates the effect of length of train, and makes it as easy to handle a train, no matter how long, as it is to handle a single car.

(b) Double protection against delays to traffic due to brake failure, since the pneumatic brake is always in reserve ready for use, if required.

(c) Maximum efficiency and safety due to simultaneous operation of all the brakes on a train in both service and emergency applications, and a perfect flexibility of manipulation.

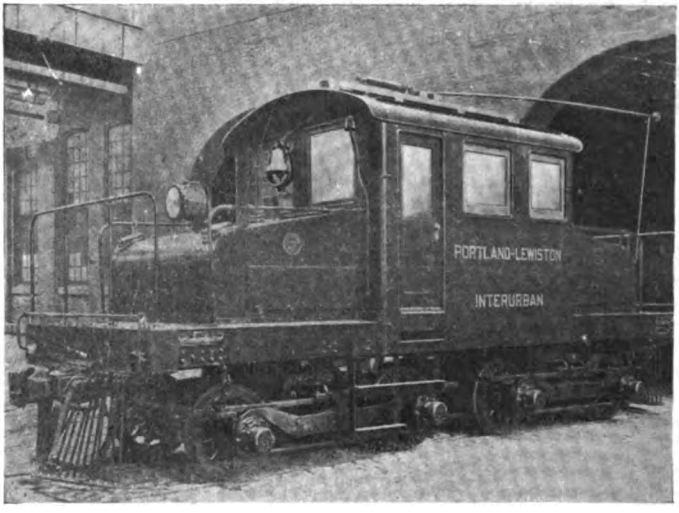
(d) Economy of air consumption.

(e) Maintenance of brake-cylinder pressure at will.

Westinghouse Traction Brake Co., Pittsburgh, Pa.

Digitized by Google

Baldwin-Westinghouse Electric Locomotives



Get the Best Service

at a minimum maintenance cost with Baldwin-Westinghouse Electric Motors.

The name Baldwin on an electric locomotive means that their mechanical construction, fitting of parts and general finish have received the same careful attention and the same quality of workmanship that have made Baldwin Locomotives famous the world over.

The name Westinghouse on an electric locomotive means that the electrical equipment embodies the same superior development in railway motor construction and control devices that has made Westinghouse Electrical Apparatus famous the world over.

Some recent Baldwin-Westinghouse Locomotives shipped or in course of construction:

600 Volt Locomotives:
Portland, Grey & Lewiston Ry.
Toledo & Indiana R.R. Co.
British Columbia Electric R.R.
Gault, Prescott & Hespeler R.R.
Guelp Radial Ry. Co.
Frederick Railroad Company

Single-Phase Locomotives:
New York, Westchester & Boston R.R.
New York, New Haven & Hartford R.R.
Boston & Maine R.R. (Hoosac Tunnel)

1500 Volt Locomotives:
Piedmont Traction Co.
Greenville, Spartansburg & Anderson Ry.

Address either company

The Baldwin Locomotive Works, Philadelphia, Pa.
Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Digitized by Google

Digitized by Google

Digitized by Google